CHAPTER 1

INTRODUCTION

1.1 GENERAL CONCEPT

Malaysia, enclave in the tropical region, has enjoy the abundance of rainfall and green landmasses, which contributed to the abundance of groundwater resource from the annual rainfall of 3,000mm and the estimated groundwater storage of 5,000 BCM (Azuhan 1990), as illustrated in Table 1.1 . With groundwater storage and groundwater usage currently at 197 Ml/d (Malaysia Water Guide, 2009) in Malaysia, groundwater resources are still underutilized.

Table 1.1: Water Resources in Malaysia

HYDROLOGY PARAMETER	TOTAL ANNUAL VOLUME (BCM)
Annual Rainfall (3,000 mm)	990
Evo-transpiration	360
Effective Rainfall	630
Surface Runoff	566
Groundwater Recharge	64
Surface Artificial Storage	25
Groundwater Storage	5000

For the state of Kelantan, where groundwater is being significantly utilized for potable water supply, is the leading state and largest groundwater operator in Malaysia. Traditionally people in Kelantan have used groundwater resource as the potable use since early civilization, before fully developed into industrial potable use in 1935 (W Ismail 2009), taking the advantage of the rich groundwater alluvial basin especially in the north region of Kelantan.

The groundwater resources of the Sg.Kelantan river basin (Fig.1.1*:Map of Kelantan Hydrogeology*) are the main sources of fresh water and also are vitally needed to supplement surface water sources. Professional and scientific practice shows that an intergranular aquifer found in Kelantan offers the greater potential in maximizing the utilization of this precious resource. It contributes to the safety of water supply and to a general improvement of groundwater quality. However, despite their importance, the groundwater resources are under stress of exploitation and contamination. The maintenance and protection of groundwater ecosystems should therefore be a major topic in the coming years in groundwater water management.

Information on groundwater resources and potential threats is also an important first step in effective source protection. The information and analysis generated by studies will support the development of local and regional groundwater strategies. Information from studies is vital since studies can provide data to support the development of a statewide watershed-based source water protection framework.

Groundwater used to be a virtually inexhaustible source of water supply, and was convenient because it was accessible, and because it continued to deliver a good quality of water. On the other hand, groundwater as well as surface water is finite resources. With the increasing rates of abstraction and the broadening scope of human activity, it has led to increased constraints on water management, including the use and protection of groundwater. Water use and water management can be divided into three stages:

Stage 1: Abundance: Water use and water pollution are low relative to available resources.

Stage 2: Depletion: Water use and water pollution are considerable relative to available resources, leading to a gradual depletion of resources.

Stage 3: Sustainable development: Water management must be implemented in such a way as to conserve good water status and avoid the depletion of resources to future detriment.

(Source: *UN/ECE Task Force on Monitoring and Assessment 2004*)

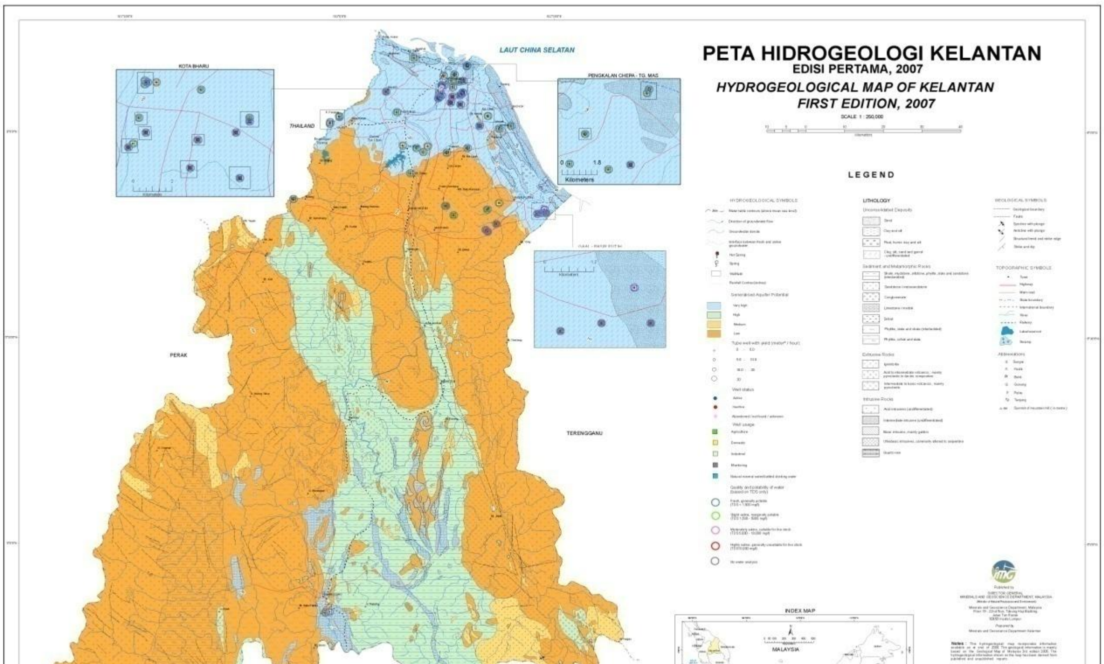

Fig.1.1 : Kelantan Hydrogeology Map: Sg.Kelantan River Basin (in light blue legend)

In Sg.Kelantan river basin, the widely observed effects are the decline of the water table as well as deterioration of groundwater quality and in certain isolated coastal areas of the basin, seawater intrusion and probably land subsidence, as of description of Stage 2. Although it might be in its premature stage 2, but with these problems growing, the awareness of the need for sustainable management of the groundwater resources, as laid in stage 3 for sustainable development of groundwater, will have to be increased.

Water management needs to be adaptive. It should take into account the specificities associated with the natural and socio-economic status of individual areas, as well as those associated with potential climate changes, while striving to achieve sustainability.

Monitoring of water quality, water levels, and water extraction in an aquifer is, therefore, of fundamental importance as a basis for groundwater resources management. Monitoring, data collection and analysis provide the information that permits rational management decisions on all kinds of groundwater resources sustainability issues.

The role and importance of the aquifers of the Sg.Kelantan river basin demand a careful and consistent assessment and monitoring of these resources. An integrated approach to monitoring design together with a unified and consistent information base on basic hydrological processes is a prerequisite for the sustainable management of its aquifers, where the already complex interplay of geology, climate and human activities that defines a groundwater catchments or groundwater body.

1.2 INTEGRATED WATER RESOURCE MANAGEMENT (IWRM)

The Global Water Partnership has defined *"Integrated Water Resources Management (IWRM)" as a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.*

The IWRM key principle is best described in the *Dublin Principles*, a set of four principles for effective and efficient water management that were the outcome of a major conference on Water and Environment held in Dublin in January 1992, which narrates that, in summary:-

- *Water is a finite and vulnerable resources, essential for life, development and environment*
- *Water development and management should be based on stakeholders participation*
- *Women plays an important role in water management*
- *Water has an economic value and should be recognized as an economic good*

(IWRM in Action, Jan Hassing et. al. UNESCO 2009)

Malaysia has yet to set and develop a National Integrated Water Resource Management (IWRM), where geographical and political context is set within to develop the national framework of policies, legislation and institutions in which water resource management in river basins and sub-basins can take place. With an exception, where recently the Federal government through Jabatan Pengairan dan Saliran (JPS) under the Ministry of Natural Resources and Environment have carried out a study to formulate a National Water Resources Policy for the Malaysia.

Malaysia has reached the development threshold that makes it necessary for the country to move to next stage of IWRM progress, i.e inter-sectoral management of water resources and its use. This implies the need to develop a policy, law and institutional framework that can support the inter-sectoral planning and coordination of water resources management.(Review of National Water Resources and Formulation of National Water Resources Policy, Ranhill Consulting Sdn.Bhd. June 2010)

A National IWRM will take into account all activities and developments, among others ecological requirements, water supply, sanitation, irrigation, land use and forestry, within each basins and sub-basin that require water or influencing the water resources, to be planned and monitored. The goal for National IWRM is for sustainability in water management with representation in environmental sustainability, social equity and economic efficiency. The thematic areas required to provide a detailed and effective water resources management, are:-

- Rivers, lakes and coastal management
- Groundwater management
- Water quality management
- Floods & drought management
- Water resources allocation

1.3 INTEGRATED RIVER BASIN MANAGEMENT (IRBM)

Integrated River Basin Management (IRBM) is defined as "the coordinated management of resources in natural environment (air, water, land, flora, fauna) based on river basin as a geographical unit, with the objective of balancing man's need with necessity of conserving resources to ensure their sustainability" (Global Water Partnership, 2000). When IRBM is implemented in river basins, it is focused towards integrating and coordinating policies, activities and practices, which addresses water and river related issues. Similar to IWRM, the implementation of IRBM requires professional capacity building and financial backing, legislative, managerial and political capacity. The main objective of the IRBM is to establish a balance between the existing natural functions of the river system and the developed aspects of the system. The management actions should fulfill the expectations of the society for industrial use, recreation, nature management, and agricultural purposes. (Council of the European Communities 2000. Directive 2000/60/EC)

1.4 GROUNDWATER RESOURCE MANAGEMENT (GWRM)

Prerequisite for developing a more informed assessments of the implications of groundwater conditions for industrial use and scientifically founded courses of action for managing the resource base, is a sound and good groundwater resources management system. These can be focused on the development of adaptive responses to water problems and policy approaches that reflect and respond to uncertainty, change and the absence of real understanding of systems and their interactions. Inherent limitations in the nature of scientific information in conjunction with the dynamic process of social and institutional change occurring in many parts of the world make the assessment at least as important as the scientific studies.

Basic research on groundwater is fundamental to any attempt to manage groundwater or respond to the problems related to groundwater use in the region. It is important to conduct further research (in spite, of many studies that have been conducted in the study area) to identify techniques for the rapid and accurate evaluation of water-balance components under the developing conditions. Development of improved water-balance models will certainly help the implementation of Groundwater Resource Management (GWRM) system in the study area.

Objectives of GWRM are set within the scope of overall water resources management i.e. monitoring, data collection and analysis providing the information that permits rational management decisions on all kinds of groundwater resources sustainability issues and achieving goals, that are:-

i. Understanding the flow system and assessing the current groundwater status,
ii. Quantifying inter-relationships between surface water and groundwater,
iii. Determining and detecting trends in groundwater levels and quality identifying actual and emerging problems,
iv. Assessing the magnitude and impact of pressures and the rate of use of the resource,

v. Assessing changes in status with time in response to the application of measures for improvement or prevention of deterioration and evaluating the effectiveness of management actions.

(source: Groundwater in large river basin, IWA publishing 2008)

A data management tool for groundwater resources data will have to be established. It is a web based GIS application that allows you to access, integrate, query, and visualize multiple sets of data. It is also a one stop shop for state-wide groundwater resources information management system. Embedded in the system, is the creation of numerical groundwater models of field problems that requires careful attention to describing the problem domain, selecting boundary conditions, assigning model parameters, and calibrating the model. It integrates multi-disciplinary data to support Integrated Resource Water Management (IRWM) and Integrated River Basin Management (IRBM). This will also increase efficiency in data download and dissemination of useful information through flexible, expandable, and user customization functionalities.

The Groundwater Monitoring System is made available for groundwater development and management and on the planning and management level there is a need for coordination between the federal agencies (Ministries, national institutions and federal departments) and the state agencies (Jabatan Pengairan & Saliran (JPS), Jabatan Air Negeri Kelantan (JANK), Air Kelantan Sdn.Bhd. (AKSB) and other state government departments).

1.5 PROBLEM IDENTIFICATION

In Sg.Kelantan river basin, while there have been many investments in exploiting groundwater resources for potable use by Air Kelantan Sdn.Bhd.(AKSB) and for irrigation purposes by Jabatan Pengairan Dan Saliran (JPS), not much attention has been paid to monitoring the condition of the resource and assessing its sustainability in terms of quantity and quality. Despite the obvious benefits of monitoring programs, it is common to find that it is the first function to be cut back when financial resources are scarce, as they are often regarded as an optional luxury that is costly and resource-consuming. Regarding groundwater monitoring, the actual situation in the Sg.Kelantan river basin is generally not satisfactory:

i. Groundwater monitoring has not been a system to be managed.

ii. Not much significant and systematic groundwater monitoring going on, except on project-wise or problem-driven and for small scale monitoring measures done by Jabatan Mineral & Geosains (JMG). In these cases, data on groundwater levels or groundwater quality are monitored within the framework of local and temporal projects.

iii. Until recently many monitoring networks in the region were developed for the assessment only of the groundwater quantitative status (water level). The quantitative aspects were the only aspects that policy makers were interested in. Groundwater quality management became an issue only recently.

iv. There is a lack of standard groundwater monitoring procedures and thus datasets from different part of the region, in many cases, cannot be compared.

Concerning the available information on groundwater resources in the Sg.Kelantan river basin, there is inadequate knowledge of both the groundwater resources and the present and forecasted demand for water. More specifically:-

i. There is a lack of detailed and reliable information on many aquifers (e.g., dimensions, hydraulic relations, volumes of water stored in both saturated and unsaturated zones, recharge rates, chemical composition of water, etc.).

ii. For many aquifers, water quantity and water use data are available but there is a significant lack of analytical information on groundwater quality.

iii. Consistent and large data gaps can be identified both temporally and geographically.

iv. Moreover, for many aquifers, the existing data are unsuitable, or poorly suited, for regulatory or planning use and irrelevant to the management process.

At general, existing data are not sufficient or reliable enough to plan regional actions for the sustainable use of groundwater. The lack of sufficient and reliable data causes a considerable risk of deterioration of the groundwater status, both quantity and quality, without sufficient warning.

1.6 THE STUDY OBJECTIVES

The abstraction of groundwater in the area is increasing by the year, in order to suffice the growing need for more water. An effective management system should be installed to control the use and exploitation of groundwater, to control the quality together with the control of land use and pollution control. Thus, the main objective of this study is to establish a Groundwater Resource Management System (GWRM) for the state of Kelantan to assess, control and ensure sustainable potable groundwater supply in terms of quantity and quality. To support and realize this objective, a few sub-objectives are to be met, as follows:

i. To define the aquifers resources of an area and watershed through a series of verified data and maps.

ii. To conduct analysis on the available data with a systematic methodology to ensure accurate final products.

iii. To propose a constant groundwater monitoring, evaluation and auditing.

To ensure that these objectives are achieved and to demonstrate the application of the groundwater management system in ensuring the sustainable potable groundwater supply, a recent survey and data gathering exercise was conducted to produce an up-to-date modeling of the study area and later to be used in the GWRM processes of monitoring and responding effect of the system.

CHAPTER 2

BACKGROUND AND PREVIOUS STUDIES

2.1 DELINEATION OF STUDY AREA

2.1.1 Geology of Kelantan

The first geological survey in Kelantan was carried out in 1922-1925 and later from 1950-1960 by Savage, followed by MacDonald, Slater and Santokh Singh (MacDonald, 1967) The geology of Kelantan is shown in Fig.2.1. The geological formations range in age from Quaternary to Lower Palaeozonic and can be divided into 3 major chronological groups, i.e Palaeozoic, Mesozoic and Quarternary (Noor, 1980) The Quaternary deposits, consists of unconsolidated and semi-consolidated sediments, mainly found in the coastal region of the state, believed to be deposited since Pleistocene times while the recent deposits is the first 13 to 15 m (Zakaria, 1970; Noor, 1980). According to C. S. Hutchison and D.N.K. Tan of Geological Society Of Malaysia, the Simpang Formation is found within the broad valley of Sg.Kelantan and its delta. Low winding ridges occur in the south, which are wider to the west and narrower towards the east.

2.1.2 General Hydrogeology of the Northern Kelantan

The major potential area for groundwater in Kelantan is the northern Kelantan, which is underlain by Quaternary alluvium, as shown in Fig.2.2. This alluvium region covers area of about 1,500 km^2 from total area of Kelantan state of 14,922 km^2, which is approximately 10% of the State area. According to MacDonald (1967), the alluvium may be of marine or fluviatile origin, but it is not always possible to differentiate the two types of deposits. The alluvium is underlain by granitic and sedimentary or metasedimentary bedrock, the latter consisting mainly of shale, sandstone, phyllite and slate. The granitic bedrock occurs generally east and parallel to the northerly-flowing Kelantan River, while the sedimentary or metasedimentary rocks are confined essentially to the western part. The sedimentary and metasedimentary rocks consist of shale, sandstones, phyllite and slate occurred in the west. The thickness of the Quaternary alluvium is from a few meters near the foot of the mountain up to more than 150 m reaching the shore. It consists of clay, sand, silt and gravels (Ang & Ismail, 1996). There are two main aquifer systems (Saim, 1997):

i. *shallow aquifer* - mostly unconfined but occasionally semi-confined, thickness normally 2-3 m and may reach up to 17.5 m. It is usually referred to as first aquifer, and

ii. *deep aquifer* - mainly confined, thickness usually more than 15 m. This deep aquifer comprises three different layers, separated from each other by semipermeable strata of silt, normally referred to as the second, third and fourth aquifer.

In the pumping test of a production well with screen located at 14-31 m carried out by Noor (1980) at Kampung Chap, Bachok, it is found that the first and second aquifer systems in this area are hydraulically interconnected as they are only separated by semi-permeable strata of silt. The pumping test affected the drawdown of observation wells located 200 m away with screen set at different depth of 6 , 36 and 96 m. However, in the earlier work by Pfeiffer and Chong (1974), it is reported that pumping test carried out at the Kota Bharu Water Works revealed no connection between shallow and deeper aquifers. So, it could be concluded that the interconnection between the shallow and deeper aquifer or leakage from the lower or upper aquifers depends significantly on the lithology of the aquifer at that particular location. Nevertheless, from the data gathered in this study strongly suggest the significant interconnection between the upper and lower aquifer systems.

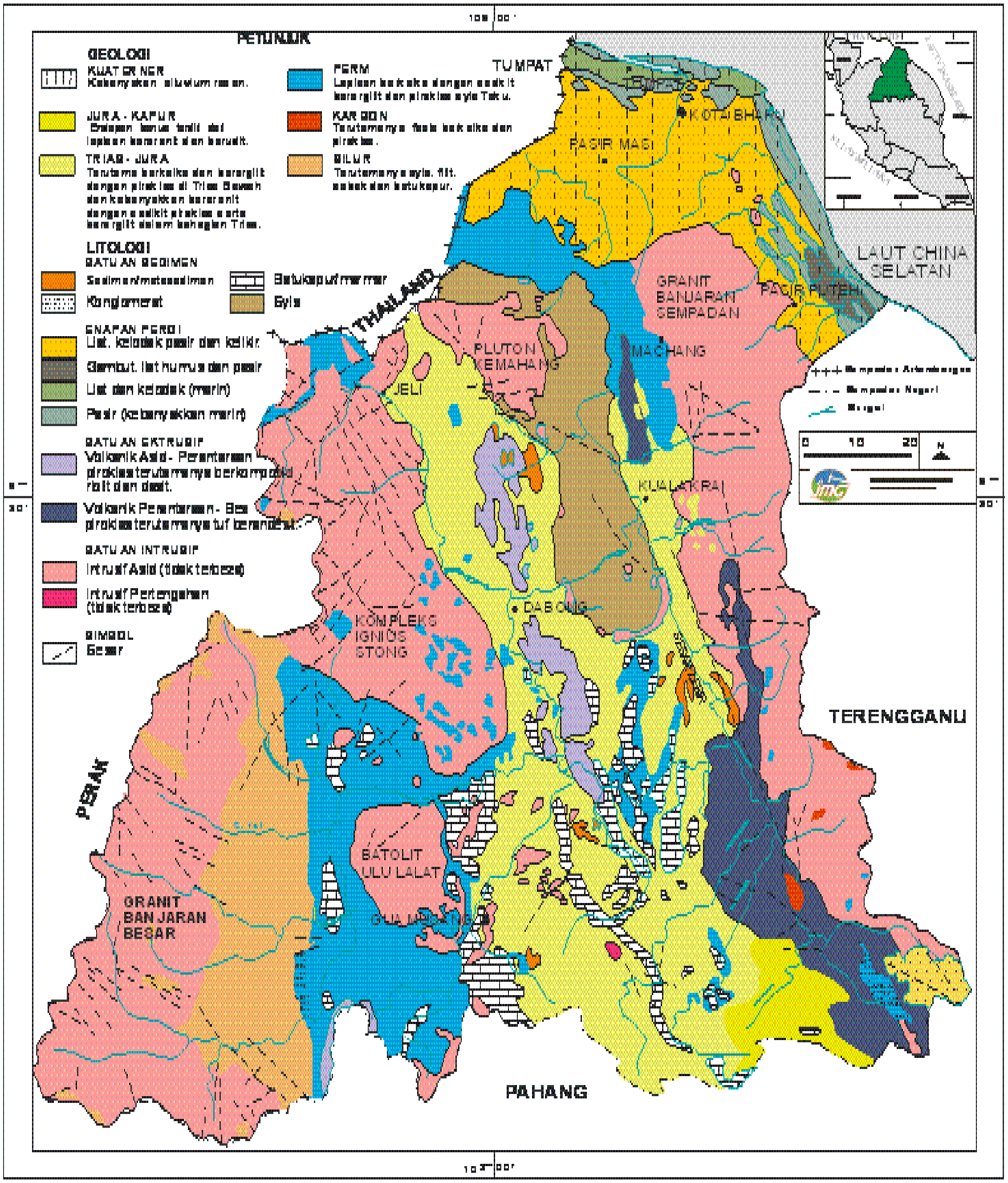

Fig.2.1: The Geology Map of Kelantan (Courtesy of JMG sources)

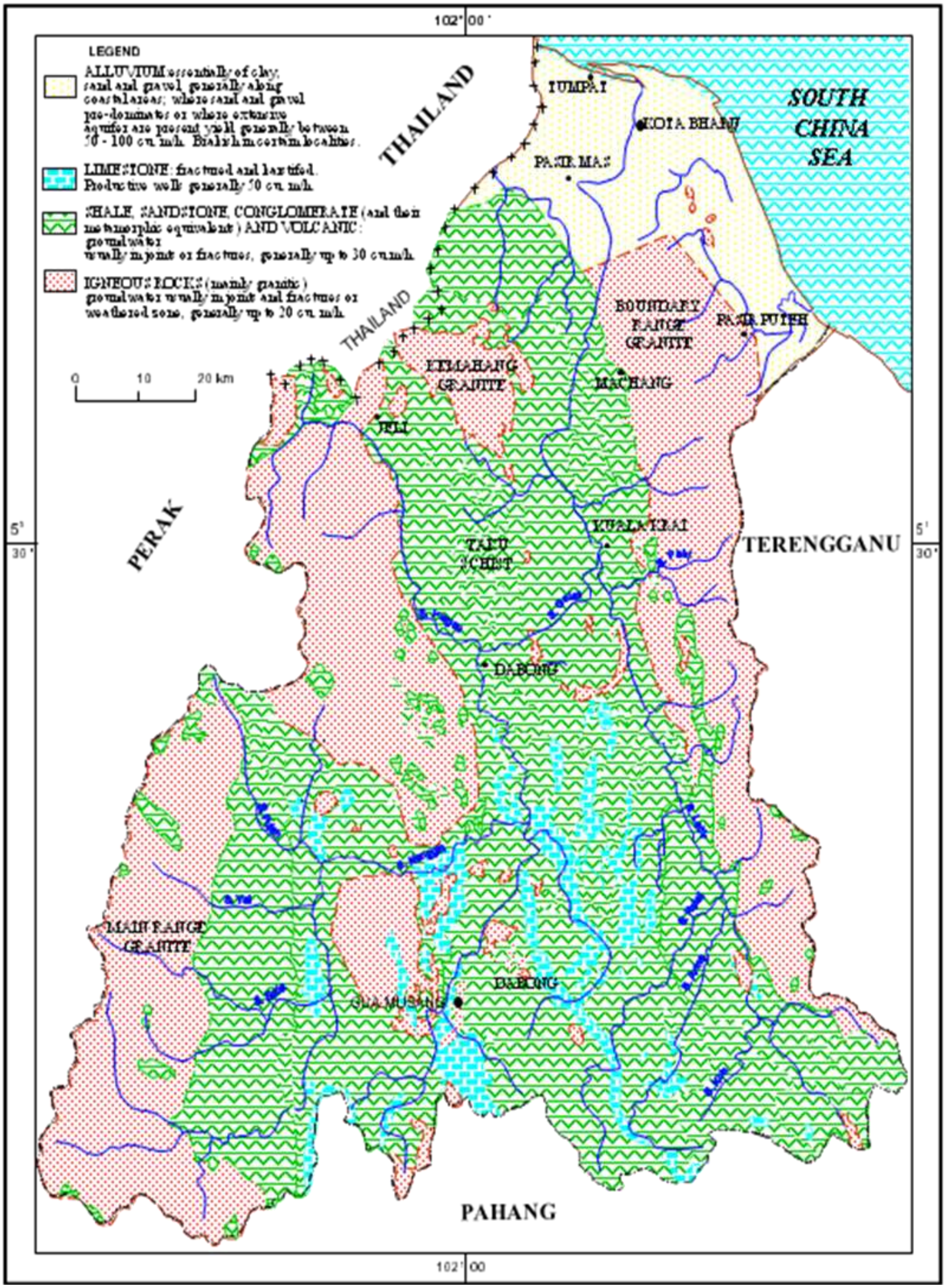

Fig.2.2: General Hydrogeology Map Of Kelantan(Courtesy of JMG sources)

The first aquifer is notably productive for abstraction in potable use because of its high recharge rate and chemically, it is not significantly high in organics minerals, such as iron and manganese. The second aquifer is generally thin and does not contain the amount of groundwater for large-scale exploitation even though in places it forms significantly thick aquifer layer. The third aquifer is the most promising in terms of production and also protection from potential pollution, but since its chemical contents in the water is fairly high and difficult to treat, the preference for potable abstraction has less priority compared to the first aquifer. The fourth aquifer is not distributed throughout the entire region of North Kelantan Basin as it forms the contact with the underlying granite. Generally, the aquifers consist of interbedded medium-sized sand to medium-sized gravel as well as some coarse gravel and the scale of interbedding varies from place to place. The percentage of course materials generally increases with depth.

Regionally, the groundwater flows north to north-east (Pfeiffer and Tiedemann, 1986). In the recent study carried out by Nuklear Malaysia in 2011, based on the result measured by the Colloidal Borescope System, the groundwater flow directions dominantly flowed towards to the north-east in the study area. However, extensive study carried out to monitor the fluctuation of groundwater level in various layers of aquifer indicates that the various aquifer layers actually show distinct trend of groundwater flow direction.

2.1.3 The Brief Description of the Study Area

The study area located at the northern part of the state of Kelantan, with Sungai Golok up to Rantau Panjang as the establish boundary at the North-west; South China sea to the state boundary of Terengganu at the North-east; and Tanah Merah and Pulai Chondong at the west of the study area. In general, this study area is an alluvium plain with the elevation less than 20 m (Figure 2.3).

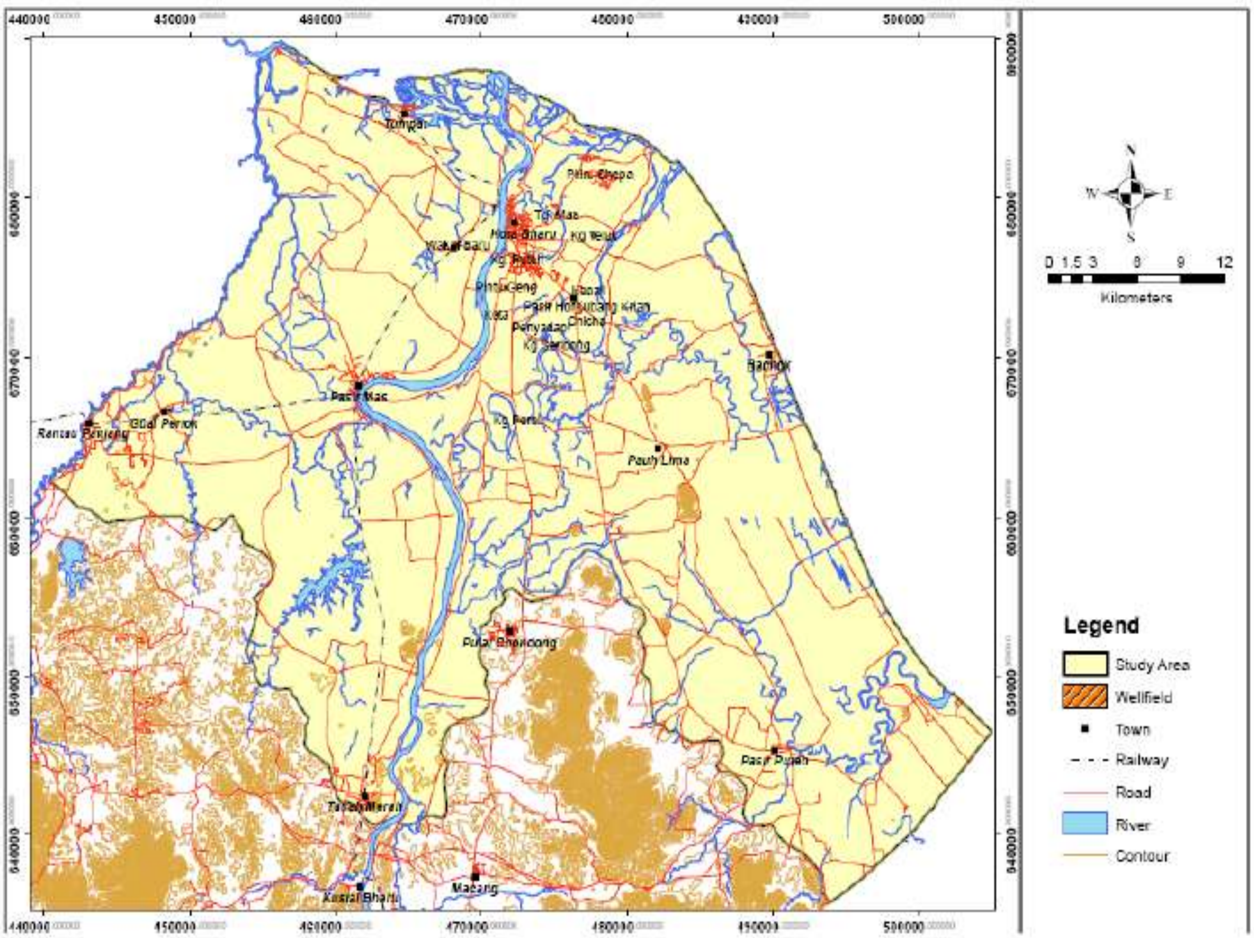

Fig. 2.3: The Study Area (Generated from GIS AKSB records)

The study area, northern Kelantan, is covered by Quaternary alluvium and underlain by granite and metasediment rocks. The alluvium covers an estimated area of about 1,500 km^2. According to MacDonald (1967), the alluvium may be of marine or fluviatile origin, but it is not always possible to differentiate the two types of deposits. The alluvium is underlain by granitic and sedimentary or metasedimentary bedrock, the latter consisting mainly of shale, sandstone, phyllite and slate. The granitic bedrock occurs generally east of the northerly-flowing Kelantan River, while the sedimentary or metasedimentary rocks are confined essentially to the west part. In general, granitic rocks are found in the east and towards the north and are parallel with the Kelantan river. While sedimentary and metasediment rocks that consist of shale, sandstones, phylite and slate are spotted in the west.

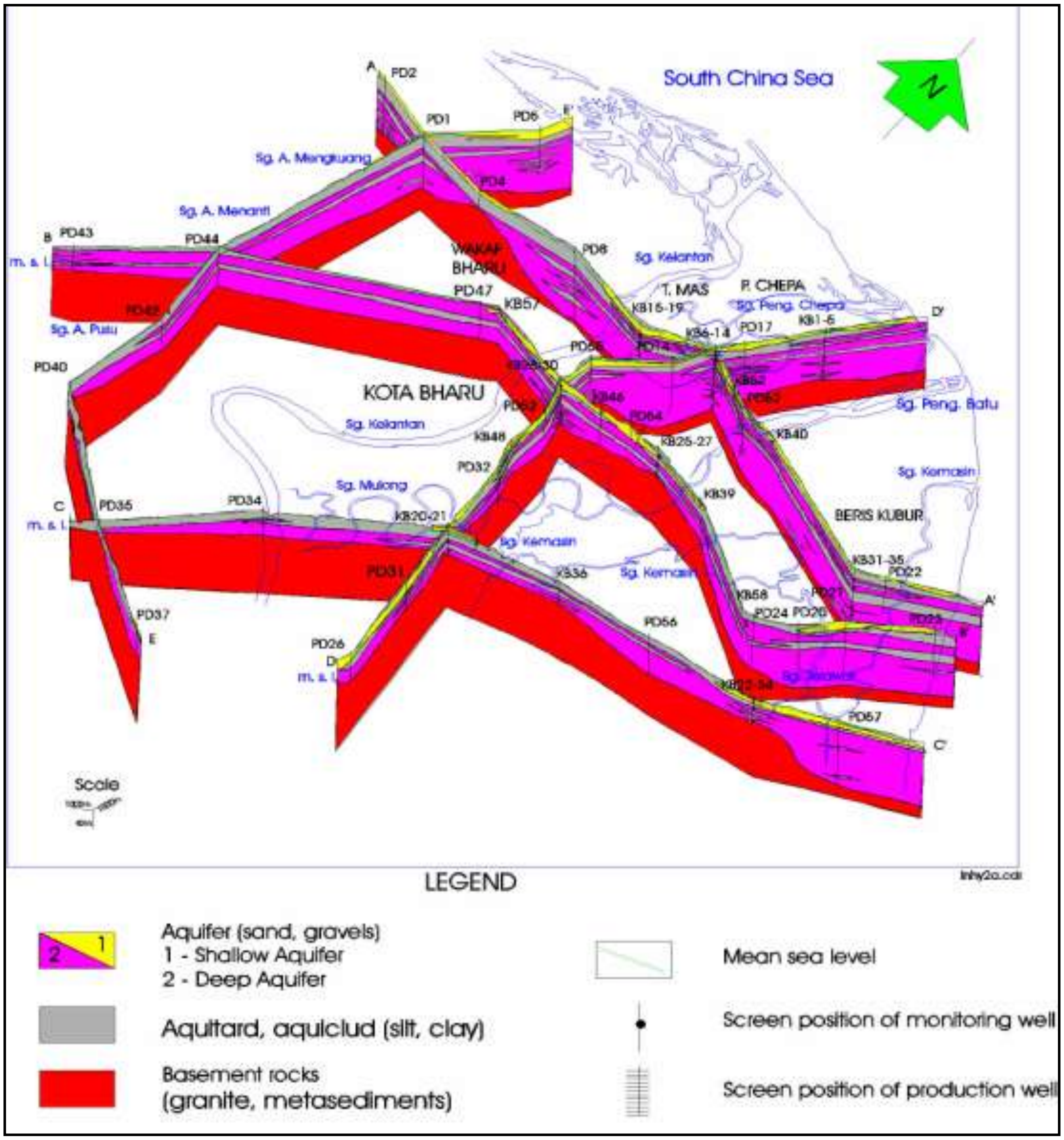

Fig. 2.4: The Fence Diagram of Aquifers In The Study Area (Courtesy of JMG sources)

Quaternary alluvium has the thickness from a few meters near the foot of the mountain up to more than 150m reaching the shore. It consists of clay layer, sand, silt and gravels (Ang & Ismail, 1996). Fig. 2.4 shows the different thickness of aquifers in fence diagram of the study area.

In the aspect of the lithology of the alluvium layer, it is highly variable horizontally and vertically due to the processes of deposition. The permeability figures ranges from 28 to 337 m/d with an average specific yield value of 0.06.

2.1.4 Landuse

The relation of landuse, landuse changes and ground conditions have to be analysed to gauge the changes in groundwater effects. Geomorphology, landuse, depth to water table, water level fluctuation and land degradation will be prepared on field data and to be used in simulation of groundwater model.

The current landuse for state of Kelantan is illustrated Fig. 2.5, where the built-up area and cleared land constitute only about 18%, agricultural use at about 38.5% and forest land with more than 42%, with other use constitute the rest.

For the study area, the landuse map is shown in Fig. 2.6. The largest landuse is agricultural use with about 60% of the area, while the built-up area at 38.24% and water bodies of 0.83%. With the large built-up area, it is anticipated that the geophysical works using SkyTEM method will be difficult and requires more correction to the data received from the surveys. It can also be said that the agricultural activities with its large landuse have some influences and effect on the groundwater quality in the aspect of nitrate and ammonium contents.

Table 2.1: Landuse Area And Percentage Of Study Area

NO.	**TYPE OF LANDUSE**	**AREA (hectares)**	**PERCENTAGE (%)**
1	BUILT-UP AREA	303,298.60	38.24
2	CLEARED LAND	1,443.60	0.18
3	FOREST	6,921.90	0.87
4	OIL PALM	11,465.10	1.45
5	PADDY	66,372.80	8.62
6	RUBBER	43,203.70	5.45
7	OTHER AGRICULTURAL	351,655.30	44.34
8	WATER BODIES	6,610.20	0.83
	TOTAL AREA:	**792,992.60**	**100.00**

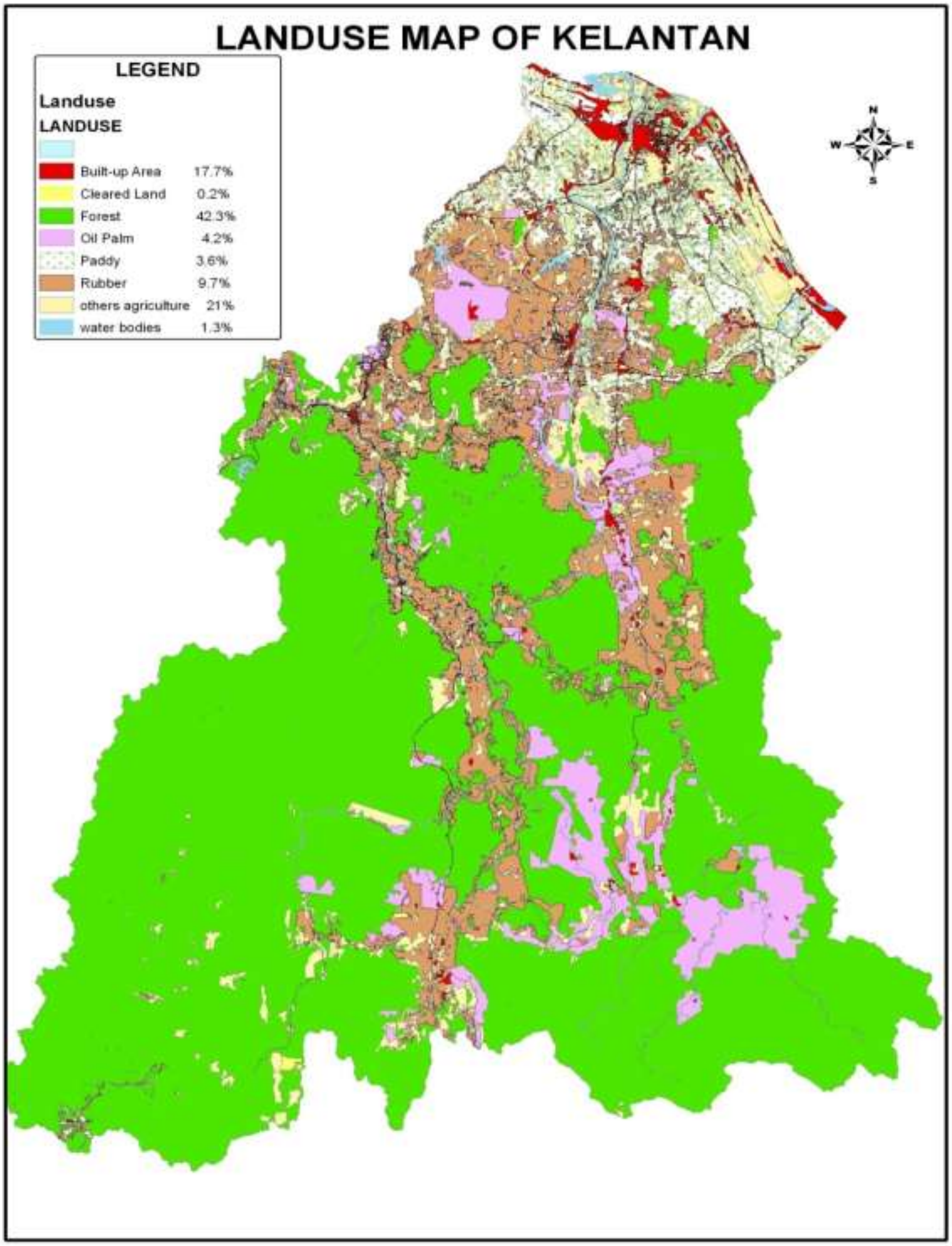

Fig. 2.5: Landuse Map Of Kelantan State (Source: GIS Data Records from AKSB

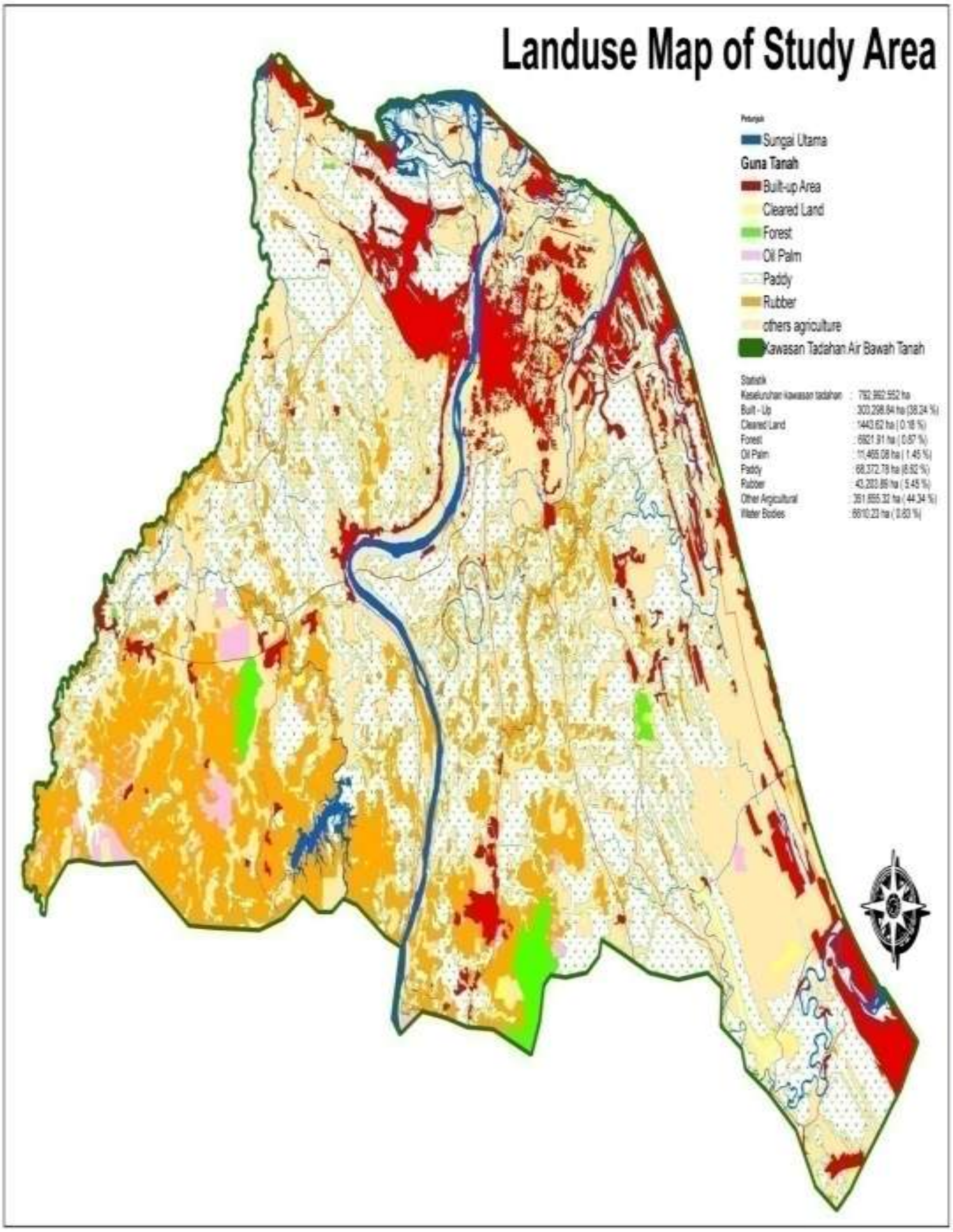

Fig.2.6: Landuse Map Of Study Area (Source: GIS Data Records from AKSB)

2.2 GROUNDWATER USAGE

In Malaysia, groundwater resources are underutilized. The use of groundwater for domestic purpose is mainly confined to rural areas. Especially in Kelantan and Perlis, groundwater is being significantly utilized for potable water supply. Groundwater is treated before bottling in the mineral water industry. For industrial purposes, groundwater is usually utilized in cleaning and cooling. Groundwater utilization for agricultural purposes is not very well developed and is normally confined to isolated agricultural areas or areas outside the many irrigation schemes. In theory, ground water resources have not yet been fully developed through exploration and research for maximum utilization of the precious resource.

For the state of Kelantan, groundwater is fully developed for potable use since 1935, taking the advantage of the rich groundwater alluvial basin especially in the north region of the Kelantan. The public water supply in Kelantan is handled by Air Kelantan Sdn.Bhd.(AKSB), through a concessionaire agreement with the State government and is responsible for the development, operation and maintenance of the groundwater water supply system in the state. Since then, Kelantan has been the largest groundwater operator in Malaysia. In the northern region, which comprises of Kota Bharu, Bachok, Pasir Mas and Tumpat district, most of the locals have their own indigenous private wells which is shallow, hand-dug and usually open type wells. Private wells predominate in the sub-urban and rural areas in the region where potable water is unavailable. But the expansion programme to extend the coverage of potable water in the state done by AKSB, have significantly made most of these private wells being abandoned or are left as supplement use during a crisis. Outside the northern region, groundwater availability is limited the certain pocket areas, namely Pasir Puteh (alluvium), Kuala Krai/Gua Musang (volcanic rock) and Jeli (igneous rock), yet to be develop and exploited. Other usage of groundwater such as agricultural purposes is prevalent for the agricultural schemes like the Kemasin-Semarak projects, the Kandis resettlement scheme and the Bendang Pauh, Meranti and Sri Pinang irrigation schemes.

Groundwater explorations in Kelantan has been under the jurisdiction of Jabatan Mineral dan Geosain (JMG), known then as, Geological Survey Department (GSD), and have assisted the Public Works Department (which was responsible for water supply before AKSB), to construct the first tube well (first generation wells) in 1935. These wells were in operation until 1979 when they replaced by the next generation wells, known as Second generation Wells. Before the construction of the second generation wells was carried out, a large scale study and systematic investigation was carried out between 1974 and 1977 by GSD with the professional assistance of the German Hydrogeological Survey Mission. Based on these survey and study, the forecasting of future water demand and proposed development programme was made available and works were underway in the 4th Malaysian Plan. The second large scale study was carried out by Syed Muhammad, Hooi and Binnie, which include field investigations and site survey, between the year 1984 and 1986. The study was further developed by Sepakat Setia Perunding in 1990. The result of the these studies was the cornerstone of the recently developed water treatment works and construction of new generation wells, known as Third generation wells.

The demand in groundwater for potable use has risen steadily over the last 30 years. The groundwater production was 36.37 MLD in 1981, increased to 45 MLD in 1984 and was 65 MLD in 1989. During the years 1986 - 2000, there was not any significant development project that was carried out and as a result, the water supply went acute to meet the water demand. Concurrently, the production from the plants also dropped to 57 MLD in 1990 with a slight increase to 66 MLD in 1993. This phenomenon was due to over pumping of water in the existing tube wells to cope with the water demand that had made the performance of the tube wells went bad to worst. Under the Bekalan Air Kelantan Utara (BAKU) project implementations in 1993, 72 nos. new Third Generation wells were constructed which had a total abstraction of 115.6 MLD. With these new wells constructed and taking into accounts the 51 nos. old wells in operation, the total group capacity of these tube wells are 184.35 MLD. Only in 2003, when the construction of new treatments plants in 8th Malaysian Plan were implemented and completed, the third generation tubewells were fully utilized and groundwater are being abstracted to be fully treated before supplying to the public. The production of groundwater in 2003 was 114 MLD. In 2009, the total groundwater consumption is 134 Ml/d, which constitutes about 41% of the total water production in AKSB's water treatment plants. The demand for groundwater in potable use is at 145 Ml/d in 2010, as fresh groundwater supply is obtained from 91 numbers of active production wells located at 13 well-fields. Groundwater for these all well-fields is drawn from shallow aquifer system except in Tanjung Mas and new wells at Pintu Geng and will increase at pace of 2.5% per year (W Ismail, 2009). The total production of potable water from groundwater sources from the year 1990 to 2010 is shown in Fig 2.7 and the total groundwater abstraction from well-fields in study area is shown in Table 2.2. The locations of existing well-fields and treatment plants is shown if Fig. 2.8.

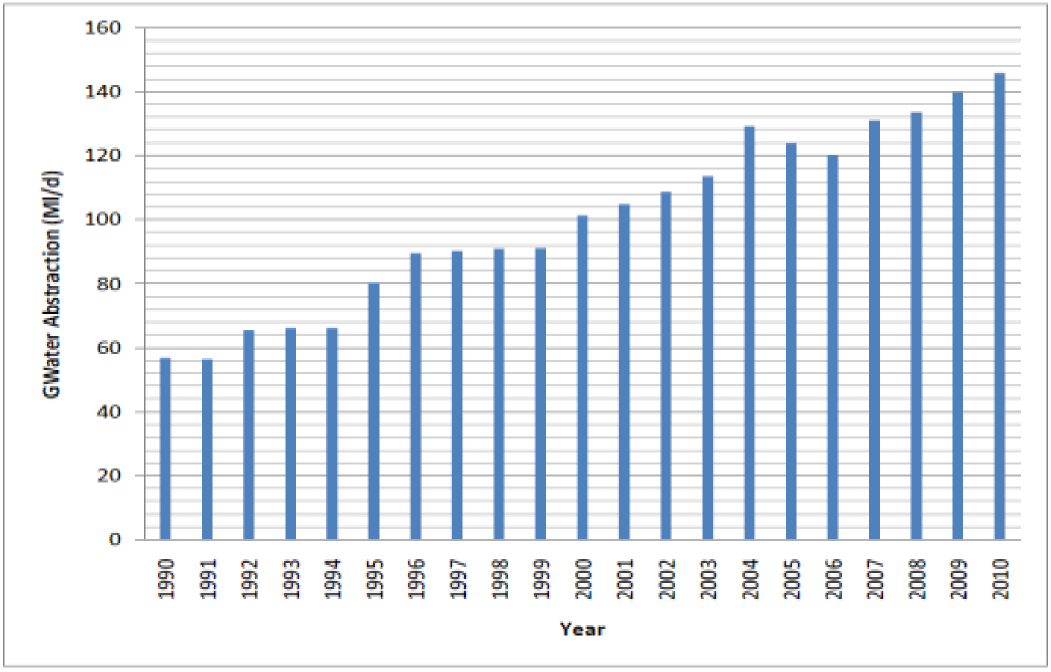

Fig 2.7: The total production of potable water from groundwater sources (1990-2010)
(Source : Air Kelantan Sdn Bhd Data Records)

Table 2.2: The total groundwater abstraction from wellfields in the study area for year 2010. (Source: Air Kelantan Sdn Bhd Data Records)

No.	Groundwater Treatment Plant	Wellfields	No.Of Production Wells	Treatment Plant Capacity (Ml/d)	Groundwater Abstraction (Ml/d)
1	**Chica, Kota Bharu**			80	**59.2**
	Zone 1	Pasir Hor	7		34.2
		Penyadap	5		
		Seribong	5		
		Pasir Tumboh	2		
	Zone 2	Kubang Kerian	5		14.8
		Kenali	5		
	Zone 3	Chica	4		10.2
2	**Kg.Puteh, Kota Bharu**			40	**44.1**
		Kg.Puteh	20		37.2
		Kg.Kota	8		6.9
3	**Pintu Geng, Kota Bharu**			8	**11.6**
		Pintu Geng	10		9.6
		Kg.Kota	8		2.0
4	**Perol,Kota Bharu**			3.2	**3.9**
		Perol	2		3.9
5	**Ketereh,Kota Bharu**			5	**3.6**
		Ketereh	2		3.6
6	**Tanjung Mas,Kota Bharu**			10	**9.3**
		Tanjung Mas	8		9.3
7	**Kg.Chap, Bachok**			4.9	**4.6**
		Kg.Chap	4		4.6
8	**Wakaf Bharu, Tumpat**			15	**12.9**
		Wakaf Bharu	9		12.9
	TOTAL:				**145.3**

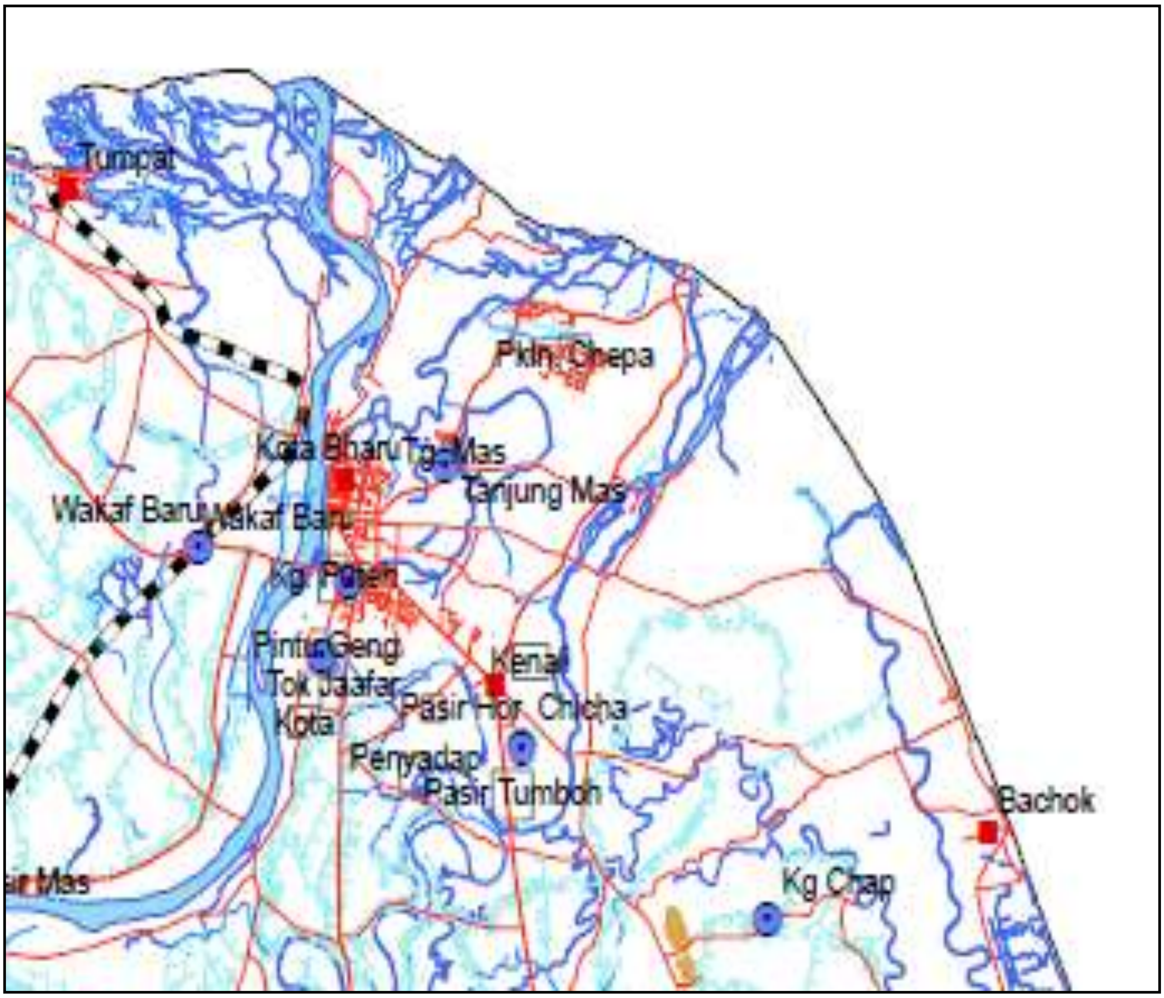

Figure 2.8: Location of Groundwater Well-fields and Treatment Plants (Courtesy of JMG sources)

2.3 PREVIOUS STUDY AND EXISTING GROUNDWATER MONITORING

A systematic investigation was carried out between 1974 and 1977 by GSD with the professional assistance of the German Hydrogeological Survey Mission, covering coastal alluvial areas in Kelantan, Terengganu and Pahang. This was followed up with another programme of groundwater investigations during the Third Malaysia Plan (1976-1980), for the states of Kelantan, Terengganu, Pahang, Kedah and Perlis successfully carried out by the GSM together with the same German Hydrogeological Mission. Before that, a hydrogeological map for Peninsular Malaysia on the scale of 1:500,000 has been prepared by Chong and Pfeiffer (1975). A series of hydrogeological activities in Peninsular Malaysia is done by Chong and Tan (1986). Areas covering the North Kelantan River Basin have been studied by GSM, which include works by Chong *et al.* (1976) that covers the area of Tumpat district, on the western bank of the Kelantan River. This study found a significant amount of exploitable groundwater sources from a number of wells in the investigated area that would be able to meet the demand of Tumpat district. This particular work has also identified the presence of up to four major aquifer layers in the Quaternary alluvial sequence, known as firstly, second, third, and fourth aquifers. In 1976, Sidhu and Pfeiffer carried out an investigative works on the western bank, which include the construction of two wells in the first aquifer to supply the village of Pengkalan Kubor. Pfeiffer and Sidhu (1977) carried out to investigate to supply groundwater for a water supply scheme in Wakaf Bharu, with requirement of 3.0 Ml/d. A hydrogeological investigation on the groundwater potential of the alluvial plain west of Kelantan River has been carried out by Ang and Kwan (1980). A considerable numbers of water wells were constructed during this investigation tapping groundwater from the first and second aquifers for the rural water supply scheme. This investigation has also contributed significantly towards understanding the hydrogeological characteristic of the area. Hydrogeological investigations to examine the potential of groundwater from the shallow aquifer were carried out by Mohd. Nazan (1985a) and Abdul Rashid (1989a).

Whereas, the investigative works on the eastern bank of the Kelantan River Basin are basically concentrated around the Kota Bharu area. These include, the works carried out by Chong *et al.* (1974), for the water supply scheme in the Kota Bharu and Kubang Kerian area, in which revealed the thickness of the first aquifer is between 15-18 m, overlain by 1.2-1.5 m of clay layer. The second aquifer is only 3 m thick (at 27-30 m depth) and the thickness of the third aquifer which is believed to overlie the granitic rock is not known but is at least 15 m. Thin layers of silt and clay separate the three aquifers. An assessment on the immediate water requirement at the particular time and a proposal for the future water abstraction system was prepared by Pfeiffer and Chong (1974). A study made by Ang and Kwan (1978) on the groundwater potential of the Kampong Panji area, Kota Bharu, has revealed that the first aquifer is overlain by impermeable/semi permeable layer of silt and clay with thickness ranging from 20-34 m thickness of the first aquifer is from 8-30 m, while the second aquifer averages l0m thick. The third aquifer exceeds 30 m in thickness. Porosity values from the tests carried out on the samples taken from the first and second aquifer lie in the narrow range of 14.5-15.5%. Abdul Rashid (1989b) carried out an investigation to study the lateral extension of the first aquifer in the Kampong Puteh of Kota Bharu district.

Further works carried out on the eastern bank are of, Doll Said (1984), which located sufficient amount of groundwater supply for a small community using 38 mm diameter well-point systems from the first aquifer which is 2-3 m thick and Mohd. Nazan (1985b), who carried out an exploration study on the availability of groundwater for domestic use and tobacco cultivation in Pasir Putih area, while Abdul Rashid (1989c) carried out an investigation on the possibility of increasing groundwater supply from 2.9 Ml/d to 4.1 Ml/d from the Kampong Chap and Jelawat waterworks.

Using radio isotopes, Khoo (1979) prepared a proposal for the use of the isotopes in the groundwater studies in Kelantan. In a proposal to carry out groundwater monitoring works in the Tanjung Mas wellfield, Bina Runding Sdn. Bhd. (1986), it is found out that the principal threats identified were saline water intrusion from the South China Sea and pollution potential from urban and industrial developments such as Batik Industries around the area.

In another study made by Noor (1980) on the extent of aquifer distribution within the Kelantan Coastal Plain, has provided an appraisal of the groundwater resources and a guide to their distribution and their order of magnitude to form a basis for regional groundwater resources development. A hydrogeological model has been constructed and verified, to provide initial assessments of the groundwater potential in the area studied. In the study, Noor (1980) concluded that the Sg. Kelantan river basin is a plain of extensive highly transmissive but anisotropic aquifers which are largely unconfined layer. Due to the process of deposition, the lithology of the alluvium in the area is highly variable horizontally and vertically. The permeability value is in the range of 28 to 337 m/d, with an average specific yield value of 0.06. Noor (1985) made an assessment based on available information at that time and estimated the through flow of the Northern Kelantan aquifer to be 174 MCM/year (~483 Ml/d). Greatest through flow is in the shallow aquifer due to higher transmissivity and the suggested allowable exploitation of groundwater at 54 MCM/year (~150 Ml/d).

The application of the concept of conjunctive use of ground and surface water was initiated by Afzal Hossain (1989). A conjunctive use model of surface and groundwater was developed to study both the ground and surface water resources availability in the coastal area of Sg. Kelantan river basin, which predicted that optimum combination of resources comprising of surface reservoir with active storage capacity of 50.0 MCM, groundwater pumping capacity of 15.0 MCM/month (~500 Ml/d) and a canal capacity of 100.0 MCM/month (~3,333 Ml/d) are required to meet the future total dry period water requirement for two major agricultural schemes (Kemubu and Kemasin-Semerak Projects) in the area. An estimation of the optimum yield of groundwater system is to be 72.25 MCM/year (~200.7 Ml/d).

Tan and Singh (1989) have carried out an investigative work to evaluate the groundwater resources that would suffice to the water supply demand of the Northern Kelantan until the year 2000. It is proposed to utilise both shallow and deep aquifers to provide raw water supplies of up to 172 Ml/d until the year 2000 for Kota Bharu and Bachok districts, and the shallow aquifer of Wakaf Bharu should be able to supply 22.8 Ml/d for the district of Tumpat. A proposed wellfield in the Pasir Puteh district can contribute 10 Ml/d, to meet the projected demand for the year 2010. The utilisation of the shallow aquifer is the best option for further development as it is readily recharged and wells are shallow (less than 20 m deep), giving rise to competitive construction expenditures and lower pumping costs.

The Environmental Impact Assessment (EIA) carried out by Sepakat Setia Perunding (1990) in the Northern Kelantan, suggests that the shallow aquifer can provide the cheapest source of groundwater in terms of construction and operational costs. Nevertheless, the EIA has also identified potential adverse long term impacts from the additional groundwater exploitation namely, drying up of existing domestic and agricultural groundwater wells through the lowering of the groundwater table, lowering of water table will lead to land subsidence, reduction of soil moisture content in agricultural soils, groundwater abstraction will lead to reduction of groundwater flow into the river, and during the dry season water from the river will be drawn into the groundwater system, thus introducing contamination to the aquifer, inland movement of the fresh / saline water interface and introduction of groundwater vertical leakage among the various aquifer layers in the system which may transfer contamination from the shallow to the deeper aquifer.

In the study of Nawang (1988) for the river-aquifer interrelationship in North Kelantan, revealed that the recharge from the river into the aquifer varies from 0 to a maximum of 8.54 m^3/d per meter width of the Sg. Kelantan river. The recharge varies with the river water level and groundwater level in the aquifer. Awadalla and Noor (1988) initiated a digital model to study the estimated recharge value to the saturated zone along the length of the aquifer. A two dimensional numerical groundwater model has been developed by Awadalla *et al.* (1989) for simulation of current and future groundwater development in the area.

A fresh/saline interface model using a Galerkin finite-element method was developed by Nawang and Kishi (1990) to investigate potential salt water intrusion resulting from the present groundwater pumping from the third aquifer in Tanjung Mas. There is a significant time difference between water level decline and movement of fresh/saline water interface, with the interface responding very slowly. Abstraction of 11,000 m^3/d resulted in a rapid drawdown in water level, but the toe of fresh/saline interface moved inland only by 250-500 m over 30 years.

Abdul Rashid (1990) has carried out a pilot groundwater monitoring system consisting of nineteen 75 mm diameter wells, was installed by the depth of wells ranges from 30-130 m. Five wells each are located in Kota Bharu and Pengkalan Chepa, and nine wells are in Tanjung Mas area. At present, there are 69 wells which are parts of the monitoring system, where the additional monitoring wells were installed by Ismail (1992; 1993a). Periodic sampling and analyses of groundwater, and measurements of head are being undertaken as part of long-term groundwater surveillance programme to monitor and manage the groundwater resources of the area.

According to Mohammed Hatta *et.al. (2001)*, the groundwater monitoring work was initiated by the Geological Survey Department (GSD) in 1989 (now known as The Department of Minerals and Geoscience (JMG)) when a network of monitoring wells was designed and built to monitor the groundwater regime in the Sungai Kelantan delta in north Kelantan. Initially, the monitoring wells were located in the northern part of the delta, subsequently the network was expanded to cover the entire alluvial aquifer system in the area. In addition to the monitoring wells constructed by the GSD, some 20 abandoned JKR wells were rehabilitated and added to the monitoring system. The monitoring network established in Malaysia such as in the northern Kelantan area represents a regional system designed to monitor changes in the groundwater regime over a regional scale. While for DOE, it is designed to detect point sources of contamination, such as from waste disposal sites of a localised nature.

CHAPTER 3

SCOPE AND METHODOLOGY

3.1 RESEARCH CONCEPTUAL FRAME WORK

3.1.1 Hydrogeological Assessment

In order to understand the nature of various hydrogeological characteristics of the study area, an assessment exercise was carried out based on the available data and taking into account the varying factors and conditions attached to groundwater system. Various parameters were studied, such as hydraulic conductivity, permeability, aquifer thickness, barrier boundary conditions etc., since these parameters are vital for the progress of the research. Identification of hydrogeological and geological conditions governing the flow system, abstraction patterns, pollution potentials and climate changes prediction were also studied.

3.1.2 Groundwater Flow Simulation

Applications of groundwater models will have to be developed in order to assess the groundwater flow, contaminants transport and aquifer effects. In this particular study, only mathematical modeling would be carried out using the most suitable software Visual MODFLOW. This modelling exercise would able to verify the representation of the real system in the modeled area. For this study, the purposes of modelling are:-

i. To better understand of the specific small area and larger regional groundwater flow system from the idealisation of the aquifer system in the study area.

ii. To simulate the flow characteristics and the future changes caused by variable discharges and climate changes in the study area.

The hydrogeological models can therefore be used in assessing the impact of changes of the groundwater system, setting up and optimising monitoring networks, and setting up groundwater monitoring system. The finding of the modeling work will enable the water operator to sustainably manage the groundwater resources.

3.1.3 Groundwater Resources Management (GWRM) System

The management of monitoring aspect of the Groundwater Resource Management System would be based on the SCADA and telemetry system. The transmitted data is automatically processed by application software, so that data that exceeded limit values/standards could be highlighted and an alarm alert system will be triggered.

WebPages with template for data retrieval and data management will be displayed on a web based system. The website would display all relevant data creating a good overview and shall function as a portal for the GWRM System giving all relevant staff in the agencies, an easy access to the data and newly updated information.

3.2 LITERATURE REVIEW AND DATA COLLECTION

In the early part of the research, few selected literature related to the present study were reviewed and analyzed, to include the followings:-

i. Well Data

   The existing well data which include historical water quality samples results were collected and evaluated before further use. These include data for production wells of AKSB and JKR, and for monitoring wells of JMG, DOE, NAHRIM and JPS.

ii. Geophysical Data

The geophysical data were gathered from the previous geophysical survey results and were evaluated in regards to data acquisition, data interpretation, methodology etc. Inaccurate data will not be used in the study.

iii. GIS Data

AKSB has installed and use ArcGIS ver. 9.3 in its mapping system and has helped tremendously in putting this research into a better prospective. The evaluation and data cleaning process need to be carried out before it can be used in the GIS application, in order to ensure the quality and accuracy of the collected GIS data.

3.3 GIS APPLICATION

Water resources engineering is concerned with the analysis and design of systems to manage the quantity, quality, timing and distribution of water to meet the needs of human societies and the natural environment (Chin 2006). GIS can help with the groundwater modeling process by coordinating data collection, providing comprehensive database management, supporting systematic model parameter assignments, conducting spatial analysis functions, and displaying model results in understandable color-map formats (Johnson 2008). The list of varieties GIS operations supportive of groundwater modeling processes, as illustrated in the table 3.1.

Table 3.1: GIS Operations Supportive of Groundwater Modeling (after Johnson 2008)

Data Management:

Database of spatial data keyed to location and depth

Capture of archived site inventory data and conversion to GIS formats

Collation of aquifer attributes data on hydrogeologic factors, hydrology and quality

Design of model grids and mesh

Automatic formulation of model input data

Visualization of input data for error checking and consistency

Statistical interpolation to assign field data to aquifer extent

Groundwater System Modeling:

Establishment of aquifer model boundary conditions

Systematic assignment of model parameter

Interactive model simulations

Sensitivity analysis aided by GIS-based parameter changes

Model Output Review:

Display of model outputs in color-coded map

Map and graphical comparisons of aquifer simulation results with field calibration data

Model reporting and archive

All the land-based maps i.e. road, river, drainage, contour, geological, land use and landcover, etc were acquired from the relevant agencies i.e Jabatan Ukur dan Pemetaan Malaysia, Jabatan Pengairan dan Saliran, Jabatan Perancang Bandar dan Desa, etc. As required, those relevant land maps were converted to the chosen GIS software format.

3.4 SOFTWARE APPLICATION

SCADA (**S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition) system software is required for data acquisition, access and storage. The SCADA system overall blueprint, including its system architecture, the full-fledged functionalities of all equipment in the system, the establishment of the database of the system, the architecture of the backhaul, to form an establishment of a comprehensive SCADA system in providing the relevant information to be integrated with other components of the Groundwater Resource Management System (GWRM). It is anticipated with proper integration with other major component of the GWRM, it will provide sufficient information for the management in identifying its direction and taking necessary steps in either to maintain the current system and production of groundwater or to decide whether to use other resources for instance surface water and when.

The other software usable in this GWRM is the modeling of the study area by the application of Visual MODFLOW software. Groundwater modeling is accomplished by using MODFLOW a modeling program developed by the USGS. This is the most widely used finite-difference groundwater model and considered a standard for groundwater modeling. The development of input files are compiled using Visual MODFLOW a commonly used pre-processor of data that is used to speed up and facilitate the development of the MODFLOW model. Development of a MODFLOW groundwater model also facilitates the use of MODPATH and MT3D, which is a USGS modeling program that extends MODFLOW for analyzing particle tracking and pollution movement. A 3-dimensional representation of the study area was created in Visual MODFLOW.

3.5 SCADA AND TELEMETRY

Wireless monitoring systems which can effectively assist management of water companies with efficient data management and cost effective. This is crucial as wireless monitoring system provides:

i. Relatively low technical manpower and less expensive human capital requirement.
ii. Relatively low cost of equipments and monitoring tools.
iii. Effective standard operating procedures.
iv. Consistently monitoring and providing real time data with low marginal error.
v. Historical data and trends for future water management studies and planning.

With excellence telecommunication infrastructure, Kelantan can provide the wireless monitoring system for the whole area. With the right technology adoption, the locals can minimize the dependency on foreign technologies, which involve huge investment and high maintenance cost. Wireless monitoring system or SCADA is generally referred to as industrial control system that usually consists of:-

i. Communication Backhaul Protocol
ii. Device Controller
iii. Remote Terminal Units
iv. Computer Database Center
v. Interfacing software (HMI)

3.6 DATA MANAGEMENT SYSTEM

A proper **D**ata**b**ase **M**anagement **S**ystem (DBMS) has to be installed in order to cater for large amounts of data that will be acquired every day. The DBMS, including GIS, has to be designed for handling all kind of data types (water levels, water quality, pumping capacity, geophysical data, etc). The database integrates collection of data records, files, and other database objects needed by an application and allows different user application programs to concurrently access the same database.

Detailed data acquisition program required for the successful implementation of the study and provide expertise to acquire the followings:-

i. Various elements of information for conceptual model such as water abstraction and contaminant sources,

ii. Geophysical Survey of aquifers for regional area and ground geophysics for local/priority areas,

iii. New and Existing Wells

- Detailed work program (elevation measurements, well logging program) for new and existing wells to be drafted.
- A procedure for construction of new wells with pumping tests to be created,

iv. Water Quality Analysis, and

v. Procedures together with the water quantity analysis, to be prepared for:-

- Water level recording including surface and ground water
- Setting spatial minimum water level, h (x,y,t) criterion function
- Setting up abstraction rate criterion Q (x,y,t)

3.7 CREATION AND CALIBRATION OF HYDROGEOLOGICAL MODELS

In general, conceptual models are approximations that describe physical systems using mathematical equations. Mathematically the model represents a simplified version of a hydrogeological system, reasonable alternative scenarios can be predicted, tested, and compared. The applicability or usefulness of a model depends on how closely the mathematical equations approximate the physical system being modeled. In order to evaluate the applicability or usefulness of a model, it is necessary to have a thorough understanding of the physical system and the assumptions embedded in the derivation of the mathematical equations. Applications of groundwater models have been developed in order to assess the groundwater flow, solute transport, heat flow and aquifer deformation, and they include physical scaled model, analogue models and mathematical models (Fetter, 1994). In this particular study, only mathematical modeling would be carried out using the most suitable software available in the market, namely Visual MODFLOW.

The modeling exercise is expected to be able to verify the representation of the real system in the modeled area. For this study, the purposes of modeling are:-

i. To improve the understanding of the specific small area and larger regional groundwater flow system from the idealisation of the aquifer system in the study area.

ii. To predict by simulation processes in the flow characteristics and the future changes caused by variable discharges in the study area.

Application of these groundwater models include water balance, gaining knowledge about the quantitative aspects of the unsaturated zone, simulating of groundwater flow and chemical migration in the saturated zone including river-groundwater relations, assessing the impact of changes of the groundwater regime on the environment, setting up and optimising monitoring networks, and setting up groundwater protection zones. The finding of the modeling work will enable the water operator to sustainably manage the groundwater resources.

3.8 GROUNDWATER RESOURCE MANAGEMENT SYSTEM

The monitoring aspect of the Groundwater Resource Management System would be based on the SCADA system. Each relevant monitoring well would be equipped with the appropriate instruments to transmit daily data to a server. The data is automatically processed by application software, so that inaccurate data and exceeded limit values/standards could be highlighted.

WebPages with template for data acquiry and data management will be displayed on a website. Furthermore, a notification/alarm would be sent to relevant agencies if limit value/standards have been exceeded. The website would display all relevant data creating a good overview and shall function as a portal for the GWRM System giving all relevant staff in the agencies, an easy access to the data and newly updated information. The system has to be designed in order to assist groundwater management and administration in:-

i. Wireless data collection and able to reduce data errors that may cause faulty alarms or supersede limits to groundwater management in providing clean and undisrupted water supply,
ii. Extraction of statistical data, by means of analysing historical data, that will ensure the right data to be used for remedial and long term water supply planning,
iii. Ensuring close monitor on ground water extraction performance, thus insuring the sustainable values and eliminating the potential water supply failure and disruption,
iv. Utilising state of the art infrastructure, that will ensure the future success of ground water sustainable supply, and
v. Minimizing the capital investment cost in short term and long term basis.

Each water production site, i.e groundwater wellfields, will be able to send information indicating real time ground water level. The water level study is a very important data which provide:

i. The rate of water level recovery from different production flow rate,
ii. Actual ground water performance of certain areas, and
iii. Actual ground water level behaviour due to external factors such as river level, nearby.

The integration exercise of the study would able to produce the list of the necessary requirement, specification and integration of the user-friendly system that would allow the water operator, AKSB to continue to provide safe, clean drinking water to the public sourced from the ground. Therefore a detail plan is produced to provide a reliable and stable SCADA system capable of transmitting real time data to provide information as in table 3.2:-

Table 3.2: Information related to SCADA

No	Information	Activity	Results
1.	The size of the aquifer (volumetric value of ground water).	Pumping the water out from the ground to certain water level.	The volume of water (V/t) will be calibrated and the time requires to meet certain water level (L/t) will be recorded.
2.	The recovery rate from specific well.	Recording the water volume extracted over time.	The water volume over time is V/t and the water level is L, The recovery rate = [(V/t)2/L2] – [(V/t)1/L1]
3.	The potential total water well production capacity	Doing several specific volumetric pumping over a specific period of time.	The recovery rate per day (WR) is recorded over a specified time.
4.	Water level that has decreasing water quality.	Specific water level pumping is recorded and water quality sample will be taken.	Each of the water levels will be recorded and the water quality test will be recorded on that specific water level.
5.	Water well actual capacity.	After getting all the information, the system software can provide a summary report.	Actual potential capacity = bad Water Level (LB) – Potential Water Well capacity (PWC).

Based on this information, an optimal management strategy for each production well can be set up daily. The minimum recharging time step for a day is established while the infiltration rates is kept constant, which fluctuates seasonally and changes throughout the year. The phenomenon of climate change can also be adapted in the groundwater management.

When a groundwater standard is reached or exceeded at a point of standards application, the water authority shall initiate a response. The proposed response to include:

i. The timeframe of commencement and conclusion of the action;
ii. A plan for continual reporting to the custodian agency, the effectiveness of the ongoing action;
iii. The estimated costs of implementation; and
iv. A plan for public notification of the proposed response.

If is required for a response to address a violation of a groundwater standard(s), then authorities to be notified, as follows:-

i. That the action was successful in achieving the objectives of the response; or in the event the original response was inadequate.
ii. Submit a report to the authorities addressing the cause of and significance of the inadequacy, and propose an alternative response.

From time to time, it is required to improve the data collection systems. Monitoring systems provide specific data, namely the data that the systems are designed to produce. Information needs may change over time. Changed information needs in turn necessitate adjustments in the data collection system.

The monitoring cycle (Fig.3.1) will eventually come into effect and suggests that the process of monitoring and assessment should principally be seen as a sequence of related activities that starts with the definition of information needs and ends with the use of the information product (UN/ECE Task Force on Monitoring and Assessment).

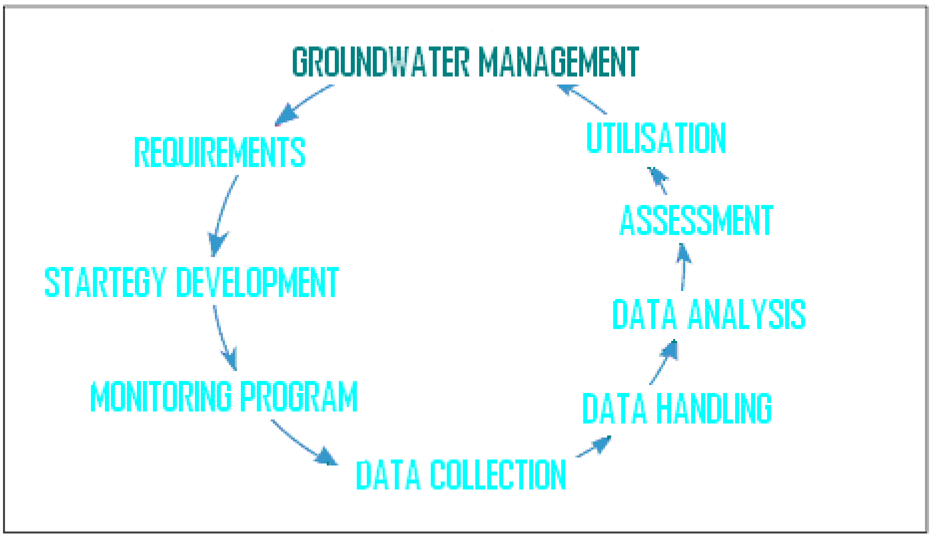

Figure 3.1: Monitoring cycle *(after UN/ECE Task Force on Monitoring and Assessment 2002)*

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 TASK IMPLEMENTATION AND WORK PLAN

The basis of this work plan is referred to the objectivity of the study mentioned before. The tasks identified for the implementation of this plan are:-

i. Data collections and evaluation,
ii. Spatial data management design,
iii. Field geophysical investigation plan,
iv. Monitoring wells development plan,
v. Raingauge and stickgauge establishment plan,
vi. SCADA system establishment,
vii. Creation and calibration of hydrogeological models, and
viii. Groundwater monitoring system operation plan.

4.2 DATA COLLECTION AND EVALUATION

The basis for data collection and evaluation in this study was centred on the data gathering and review of information on site, i.e at the wellfield, geophysical data, the area physical and built environment, and socio-economic information available from the study area. Data collection comes from various fields, such as wells data, geophysical data and biophysical resources data.

The data will be stored and managed in databases, before it can be prepared to house all data collected from drawings, documents, and other records in systematic domain. Data would be classified and organised for efficiency and easy retrieval according to several lists of attributes and there should be amended following completion of need analysis. The database server would be selected based on the amount of data involved, the type of data to be stored and the type of retrieval system to be implemented.

4.2.1 Well and Well-field Data

The data from past studies and development records of production wells or monitoring wells would be gathered and screened for its reliability and accuracy of the data. The data was collected from various agencies, namely AKSB (then JBA/JKR), JMG, DOE, and consultants/contractors, that were involved in most of the construction works of the wells and some reports were prepared dated 40 years ago.

Elements information, such as the exact well location, well depth, elevation and numbering system needed for the data collection, was found to be incomplete and missing from some records. Some other previous data on drilling activities, details of exploration wells and pumping tests were not updated and safe kept and thus has caused some limitations on compilation and analysis of the hydrogeological data. The amounts of data were limited and difficult to obtain from various agencies and departments such as JMG, AKSB Sdn. Bhd., and DOE. There were no official collaboration in data sharing among the various agencies, except mutual understanding in giving out data for departmental use. Consequently, the data collection exercise were time consuming more than expected, as data has to be salvaged and searched from these agencies. Most wells sites were revisited to carry out new survey works.

The list of wells at the wellfields are listed in Appendix A. There are a total of 164 wells out of which 105 wells are production wells and 59 wells are categorize as monitoring wells. The production wells are located in 13 well fields and all wells are actively in service, except for Kg.Teluk wells which are domant at the moment of time and 18 wells that are closed or unused, as shown in Appendix B.1- B.14. While the monitoring wells are mostly managed by JMG, NAHRIM and DOE for their routine water level and quality monitoring and data gathering exercises.

4.2.2 Geophysical Data

The geophysical data will be useful in the model creation and simulations for the settings of parameters in boundary conditions and characteristics. A number of geophysical investigations were carried out in study area in the years 1970s to produce aquifer resources mapping and hydrogeological study results and wells construction. Not many wide-scale geophysical investigations were carried out, except for the Geoelectrical Investigation done by Prof.Dr.H Flathe, from BGR in collaboration with German Hydrogeological Mission in 1974 to produce aquifer resources mapping and hydrogeological study results for wells construction. The Appendix D, shows the the excerpt report of results of the surveys.

The data collection and examination could include those available from survey done by the German Hydrogeological Missions and later investigations by JMG (the then GSD) and others.

The parameters setting for boundary conditions and characteristics in the hydrogeological model creation, was using geophysical data interpretations and results.

4.2.3 Biophysical Resources

Biophysical resources are soil, nutrients, water, plants and wildlife. Information on these resources can be used to assess how well landscapes conserve soils and recycle plant nutrients and how the condition of landscapes is changing. Information on these physical and built environment including topography, landuse activities, surface soil and geology, surface water hydrology (rainfall, water level in rivers and lakes), water quality, socioeconomic/industrial activities, pollution sources etc. These data can be gathered in the GIS representation before an evaluation could be carried and being transfered for inclusion into the implementation plan. The raw data will be subsequently uploaded into GIS.

4.3 SPATIAL DATA MANAGEMENT DESIGN

Geographic Information System (GIS) has been used in many applications of groundwater assessments and modeling, primarily to represents large spatial data in the application involved. GIS has the capability to integrate the surface water and groundwater hydrology to be managed in data system and applied to models created from it. The GIS assisted database system would help to apply groundwater management practices such as; proper groundwater resource management in terms of groundwater quality & quantity, Integrated management of water, landuse and the environment; to optimize pumping rates with respect to the capacity of the aquifer system, and to prevent groundwater quality deterioration through proper monitoring & evaluation. Raw spatial data are taken from aerial photos, maps, ready GIS data, etc. All data collected from secondary sources and the field would be entered into the system that may also involve data conversion.

A systematic approach of groundwater management must involves the groundwater system assessments in hydrologic equation-balance, pumping rates of groundwater abstraction and the effects from it, and water quality evaluation. Human factors in climatic and environmental changes will be taken into account that might affect the groundwater conditions, given the natural hydrologic and geologic conditions it contained.

In this study area, the unconfined aquifers play a direct role in the linkage function between surface water and groundwater resource where groundwater makes some contribution to stream flow and rivers lose some water by outflow to groundwater. Any changes that may occur in between may affect the flows in either rivers or groundwater, particularly pumping wells activities that can change quantity and directions of flow between rivers and aquifers in respond to the abstraction rates occurred. A river and groundwater flow relation in flow model can therefore be developed and simulated. The design will be able to offer the linkages to hydrogeological conceptual model and groundwater model, using the agreed spatial coordinate system. The integration would facilitate implementation of the plan and subsequent groundwater monitoring operations.

A management system of river-aquifer decision tool support system can also be developed in this North Kelantan River Basin. This GIS aided management tool will be used to administer daily groundwater production, contingencies plan, recharge and discharge management, and surveillance on water quality, so as to improve the North Kelantan River basin’s area management strategies.

Groundwater systems are often represented using gridded data; grids are used to efficiently create and visualize spatial distributions for pre- and post-processing of the model (Radin 2006). GIS data grids and shapefiles are then used to be integrated with modeling software, such as MODFLOW, the modeling tool for this study. The integration will involve the data inputs sets for hydrogeologic parameters, boundary conditions and initial elements. Coverage area in shapefiles to represent the rivers, landuse and production wells. Then the geoprocessing method is used to create polygons with aquifers characterization, rainfall, evapotranspiration, which then be able to generate groundwater recharge arrays and allowable abstraction rates arrays over the area.

4.4 FIELD GEOPHYSICAL INVESTIGATION PLAN

The purpose of this plan is to gain the degree of aquifer resources in Kelantan that would add to the past historical data, generally available in North Kelantan, using appropriate technique, for regional and local area investigations especially the important zones that require more detailed aquifer profiling.

The result of this plan will be a spatial distribution of aquifers mapping across the study area that will suited for identifying the potential aquifers development in the future and areas necessary for placement of monitoring wells for the sustainable management of groundwater for the area.

This vast potential of groundwater in the study area needs to be protected. However, no comprehensive studies have been carried out, to identify the productive aquifers over the vast tract of alluvium. The groundwater regime and the aquifer characteristics must be fully understood and comprehend in order to have an effective monitoring system. A wide-ranging and overall study has to be done, involving geological & geophysical (including airborne) investigations, pumping tests to determine the hydraulic parameters of the aquifers, groundwater modelling, sampling and analysis. The data obtained will be used as inputs for the development and establishment of an effective groundwater system.

4.4.1 Airborne Time domain Electromagnetic (SkyTEM)

With ground surveys only, effort to identify and map these aquifers will take considerable time and laborious. SkyTEM, a helicopter-borne transient electromagnetic (TEM) technique, provides a viable alternative to rapidly and efficiently map these aquifers for the regional area coverage technique and using ground geophysics methods for local area investigations.

This new method developed in Denmark especially with focus of surveying ground water aquifers and condition would be planned in the study. SkyTEM is a time-domain, helicopter-borne electromagnetic system originally designed for hydrogeophysical and environmental investigations (Esben Auken et al, 2009). It is an airborne geophysical method suitable for geology survey, for down to a depth of 400m below terrain, the only airborne method developed specific for ground water mapping purposes. This technique is frequently used for hydrogeological mapping for locating groundwater reservoirs. Daily production could reach 200km profile equivalent to $40km^2$ and equipment borne by a helicopter, employing the transient-electromagnetic technique (TEM) for groundwater exploration. It has proven to be a very effective geophysical tool in mapping groundwater aquifers, especially in alluvium areas. SkyTEM has recently been employed in Malaysia for groundwater exploration in Batang Padang District, Perak and in the coastal areas of Selangor. General operation of the SkyTEM operation is shown in Fig. 4.1.

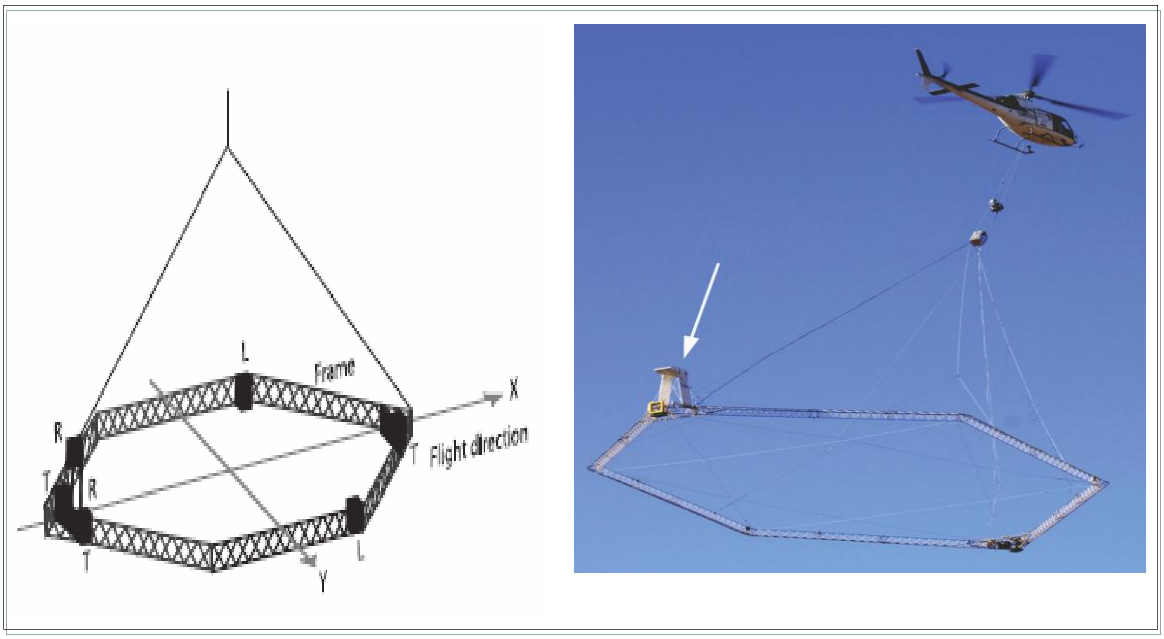

Fig. 4.1: The figure shows an outline of the transmitter frame with attached devices, tilt (T), lasers (L) and receiver coils (R). The transmitter wires are attached to the octagonal lattice frame.

A key feature in the processing is the use of an integrated interactive GIS map where the helicopter location is highlighted. Combined with proper GIS themes, it is in most cases possible to explain most features in data, e.g. that the sudden increase in altitude and somewhat coherent noise is an effect of the helicopter crossing a power line, that the lasers get bad reflections because the helicopter is moving across a forest, etc.(Esben A. *et al*, 2009).

When implemented later, the SkyTEM will be employed as the single main geophysical technique to be employed for the development of a GWRM system in North Kelantan. It is recommended that the fly line spacing of 200 m and a sampling interval of 20 – 30 m be engaged in this setup.

SkyTEM has also its limitation in detailing the geophysical survey in built-up area and hard-standing surfaces. The alternative to the problem is to employ the Regional ground transient electromagnetic (TEM) survey method.

4.4.2 Regional ground transient electromagnetic (TEM) survey

This method is an alternative to the SkyTEM survey, where hard surfaces and airborne restricted areas is not possible by SkyTEM method. Ground TEM technique would be the best substitute for SkyTEM in alluvium environment. It has the facility to be used as, a mapping and sounding tool. The possibility to map the study area is practically achievable, with the changes in apparent resistivity values which directly translate into changes in subsurface geology at various depths. It would then be possible to select profiles and carry out 1-dimensional (1D) inversion by obtaining information on the subsurface layering. This technique 1D inversion will provide information on the thickness and true resistivity values of each layer. The penetration depth is considerably less than SkyTEM technique and important information related to the basement of the lowest aquifers could be lost, which is crucial for future ground water modelling.

The TEM technique involves transfer of primary magnetic flux into the ground, created by passing current through a wire loop. The returning secondary magnetic field will then intercepted to provide indication of the subsurface profiles.

The equipment used for the ground survey should be able to penetrate to a depth of about 150 m below ground level, depending on the geology. Typically a rectangular 40m x 40m loop size will be suitable for the depth of about 150 m. The spacing should be decided based on the different conditions and nature of interest. The typical ground TEM survey method is shown in Fig. 4.2.

The raw data from the fields are obtained in transient voltages which then be changed into apparent resistivity values. Subsequently, the inversions are carried out using specialized proprietary software.

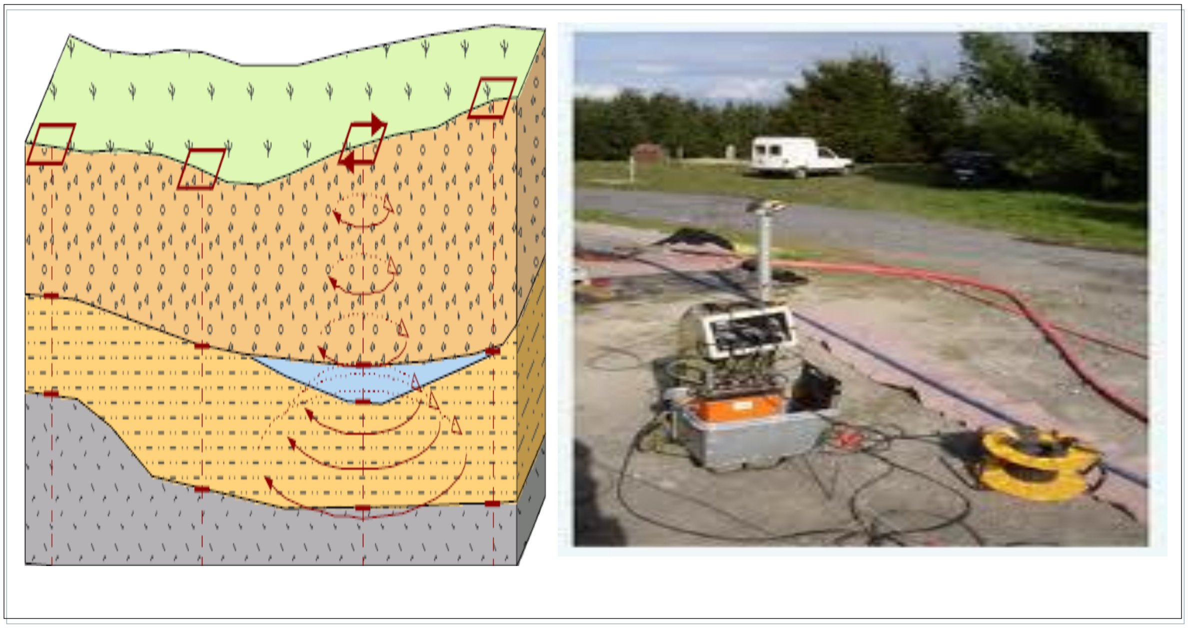

Figure 4.2: Typical Ground TEM survey method at site

The resistivity of ground water varies from 10 to 100 ohm•m. depending on the concentration of dissolved salts. This makes the resistivity method an ideal technique for mapping the saline and fresh water interface in coastal areas. Table 4.1 shows the different resistivities of common rock, minerals and chemicals used in the interpretation of the readings in resistivity meters at site (Loke M H, 1999). The main output of the ground TEM geophysical investigation is a 1D layered earth resistivity-depth profile for each individual line. It is also possible to produce apparent resistivity contour maps which will reflect changes in subsurface geology at selected delay times (windows/gates) The later delay times indicate a deeper depth of penetration.

Table 4.1: Resistivities of common rocks, mineral and chemicals *(Source JMG)*

Material	Resistivity (Ω•m)	Conductivity (Siemen/m)
Igneous and Metamorphic Rocks		
Granite	$5x10^{3}$ - 10^{6}	10^{-6} - $2x10^{-4}$
Basalt	10^{3} - 10^{6}	10^{-6} - 10^{-3}
Slate	$6x10^{2}$ - $4x10^{7}$	$2.5x10^{-8}$ - $1.7x10^{-3}$
Marble	10^{2} - $2.5x10^{8}$	$4x10^{-9}$ - 10^{-2}
Quartzite	10^{2} - $2x10^{8}$	$5x10^{-9}$ - 10^{-2}
Sedimentary Rocks		
Sandstone	8 - $4x10^{3}$	$2.5x10^{-4}$ - 0.125
Shale	20 - $2x10^{3}$	$5x10^{-4}$ - 0.05
Limestone	50 - $4x10^{2}$	$2.5x10^{-3}$ - 0.02
Soils and waters		
Clay	1 - 100	0.01 - 1
Alluvium	10 - 800	$1.25\ x10^{-3}$ - 0.1
Groundwater (fresh)	10 - 100	0.01 - 0.1
Sea water	0.2	5
Chemicals		
Iron	$9.074x10^{-8}$	$1.102x10^{7}$
0.01 M Potassium chloride	0.708	1.413
0.01 M Sodium chloride	0.843	1.185
0.01 M acetic acid	6.13	0.163
Xylene	$6.998x10^{16}$	$1.429x10^{-17}$

The other significant aspect is the present of spiky changes in apparent resistivity data, either from low to high or vice versa. This is described on the map as a sharp gradient due to either the saline/fresh water interface or the boundary between alluvium and hard rock.

4.4.3 Resistivity and Induce Polarisation (IP) technique

At present, the resistivity and IP technique is the most widely used geophysical technique in groundwater exploration in alluvium area. It is favoured over the usual technique, as it is able to detail and map the subsurface geology effectively. The current feature in resistivity instrumentation permits a 4/8/12 channels input in which will provide a better acquisition of data. This equipment offers the 2D resistivity imaging survey coupled with a minimum of 56 electrodes configuration. However, field tests to be carried out prior to the actual field data acquisition to be used for the survey in order to establish the most suitable electrode configuration and electrode intervals.

This resistivity method includes passing a direct electrical current of a pre-determine strength into the earth through two electrodes. Several electrode arrangements are possible; Wenner, Schlumberger (Figure 4.3) and dipole-dipole are the most common. The resulting potential distribution is measured between two potential electrodes, in a position centre between them. Subsequently, the apparent resistivity, ρ_a, can be deduced from the current strength, the potential and a geometrical factor k, correlated by the type of electrode configuration.

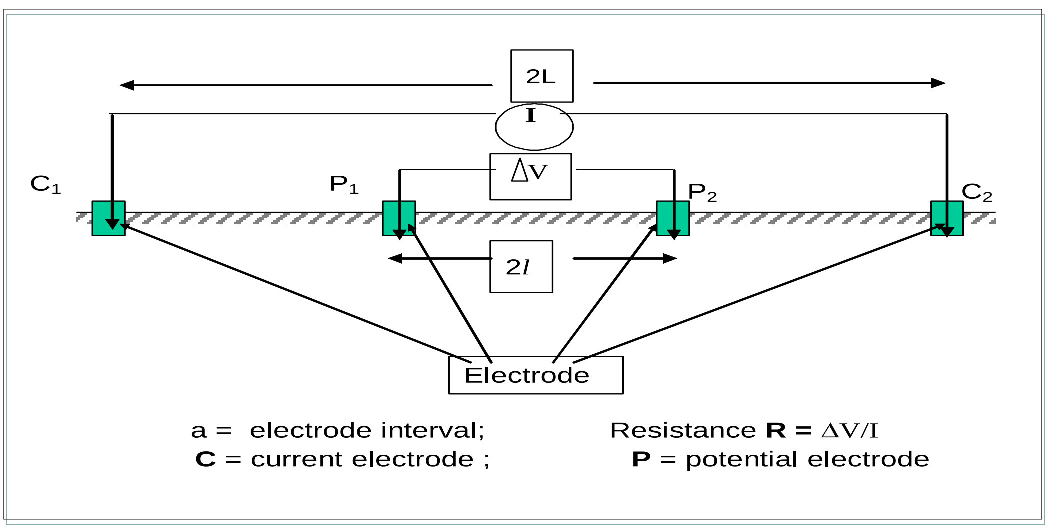

Figure 4.3: Schlumberger electrode configuration

Raw field data is to be scrutinised for quality checks and should be consistent before it can be processed. Modern day field equipments can do this processing and checks on-site. RES2DINV or EARTHIMAGER software will be used to inverse of the 2D imaging data. The software will further validate and verify for errors before the inversion proceed. A sounding curve will be produced from the apparent resistivities, plotted as a function of the electrode interval. The sounding curve can then be interpreted using curve-matching technique to produce a 1D model of the subsurface. The 2D imaging data can be presented in resistivity-depth profiles for each individual line. Any changes in resistivity distribution in the lateral or vertical line will reflect the changes in the geology of the subsurface. An illustration of the 2D inversion is shown in Fig.4.4.

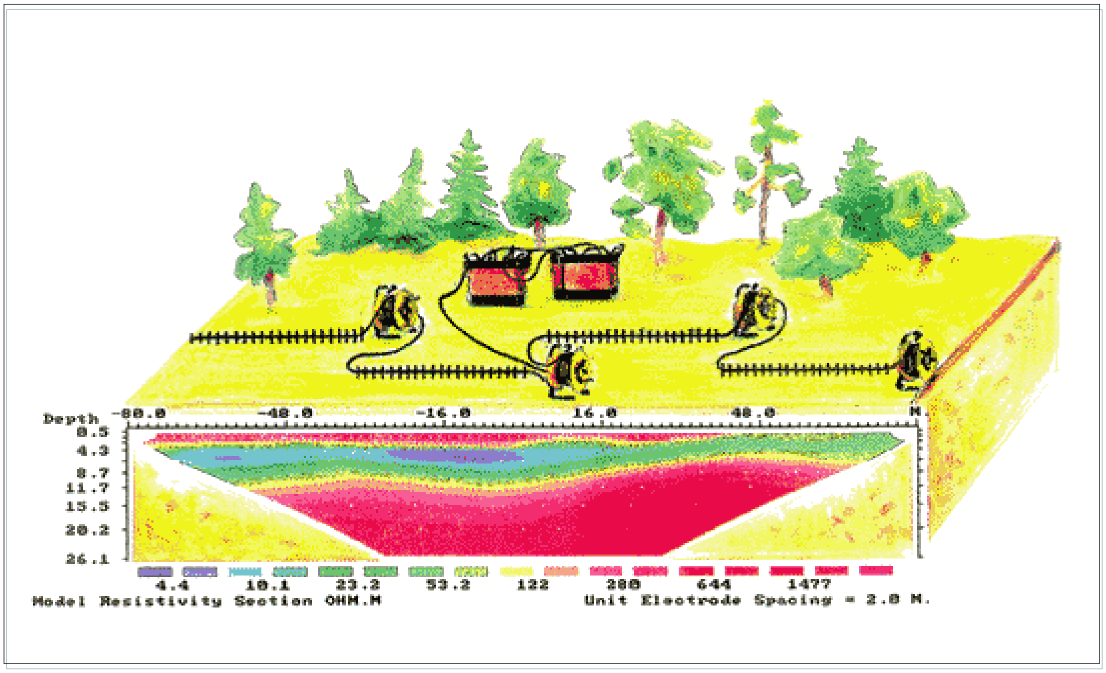

Figure 4.4: General setup and the resulting image processed by 2D inversion

4.5 MONITORING WELL DEVELOPMENT PLAN

This study on groundwater management for Sg.Kelantan basin builds the assessment on the regional groundwater availability, in which can be implemented for the national groundwater assessment as part of the science strategy to meet nationwide water on water availability and its quality checks. In order to implement the task, an establishment of a groundwater monitoring system is inevitable. The monitoring programme is carried out primarily to:

i. Acquire a continuous and updated data on groundwater manually;
ii. Observe on groundwater quality, based on the monthly data acquisition;
iii. Oversees and manage the groundwater supplies, which includes monitoring against over pumping, indicated by the decline of groundwater table and salt water intrusion in the coastal area and exercising the safe yield policy on the amount of water that can be withdrawn from an aquifer annually without causing undesirable effects;
iv. Having a mitigation action against pollution from point and non-point sources, which include sanitary landfills and waste disposal facilities for point source and for non-point sources include the, leakages from sewerage and septic tanks, urban runoff, and infiltration contaminated by agricultural products.

4.5.1 Existing Monitoring Wells and its programmes

The existing groundwater monitoring system was designed and implemented for the Kota Bharu, Tanjung Mas and Pengkalan Chepa areas in 1989 by JMG, as a pilot study and was followed by a system of collection of groundwater samples and measurement of piezometric levels.

JMG has constructed 69 monitoring wells in various parts of Kelantan River Basin since 1989. Water samples and groundwater levels in the monitoring wells were acquire in monthly intervals. The monitoring wells were constructed as individual well and in some places, a cluster of a few wells at the same location, namely the KB1-5, KB6-14, KB15-19, KB20-21, KB22-24, KB25-27, KB28-30, KB3l-35, KB59-60 and KB62-64 which are the monitoring wells installed as clusters at different locations able to monitor groundwater levels and quality of the different aquifer layers. As examined at site, the monitoring wells were mainly constructed within the compound of the groundwater treatment plants and water storage tank sites, for security reasons and vandalism. These monitoring wells have been the mechanism for continuous observation and monitoring of the groundwater quality and piezometric heads ever since.

The list of monitoring wells are shown in Table 4.2: List of JMG's monitoring wells, Table 4.3: List of DOE's monitoring wells, Table 4.4: List of NAHRIM's monitoring wells. In GIS format, the locations of the existing JMG, DOE and NAHRIM monitoring wells are shown in Fig. 4.5.

Table 4.2: List Of JMG's Monitoring Wells

No	Well ID	No HYDROdat	Easting	Northing	Location	Elevation (m)	Depth (m)	Diameter (mm)	Screen Depth	Status
1	KB 1	PD000066	478112	681482	Loji Air Pengkalan Chepa	5.931	100	75	98.5-100.0	Active
2	KB 2	PD000067	478109	681481	Loji Air Pengkalan Chepa	5.925	87	75	85.5-87.0	Active
3	KB 3	PD000068	478106	681481	Loji Air Pengkalan Chepa	5.872	68.5	75	67.0-68.5	Active
4	KB 4	PD000069	478104	681481	Loji Air Pengkalan Chepa	5.847	59.5	75	58.0-59.5	Active
5	KB 5	PD000070	478103	681483	Loji Air Pengkalan Chepa	5.794	24.5	75	23.0-24.5	Active
6	KB 6	PD000071	475211	678945	Loji Air Tanjung Mas	4.487	129	75	127.5-129.0	Active
7	KB 7	PD000072	475211	678947	Loji Air Tanjung Mas	4.438	99	75	97.5-99.0	Active
8	KB 8	PD000073	475210	678949	Loji Air Tanjung Mas	4.523	80	75	78.5-80.0	Active
9	KB 9	PD000074	475212	678949	Loji Air Tanjung Mas	4.493	55.5	75	54.0-55.5	Active
10	KB 10	PD000075	475174	678991	Loji Air Tanjung Mas	4.648	31.5	75	30.0-31.5	Active
11	KB 11	PD000076	475122	678959	Loji Air Tanjung Mas	4.501	32	75	30.5-32.0	Active
12	KB 12	PD000077	475215	678949	Loji Air Tanjung Mas	4.488	32	75	30.5-32.0	Active
13	KB 13	PD000078	475111	678894	Loji Air Tanjung Mas	4.408	31.5	75	30.0-31.5	Active
14	KB 15	PD000080	472560	678352	Tangki Air Jalan Merbau	6.571	126.5	75	125.0-126.5	Active
15	KB 16	PD000081	472573	678341	Tangki Air Jalan Merbau	6.581	110	75	108.5-110.0	Active
16	KB 18	PD000083	472572	678339	Tangki Air Jalan Merbau	6.546	65.5	75	64.0-65.5	Active
17	KB 19	PD000084	472569	678337	Tangki Air Jalan Merbau	6.466	28.5	75	27.0-28.5	Active
18	KB 20	PD000085	472425	666130	Perol Booster Pump	8.839	41	75	39.5-41.0	Active
19	KB 21 **	PD000086	472427	666128	Perol Booster Pump	8.811	24.5	75	23.0-24.5	Active
20	KB 23	PD000088	486852	664740	Loji Air Jelawat	3.578	26.5	75	25.0-26.5	Active
21	KB 24	PD000089	486855	664739	Loji Air Jelawat	3.609	7	75	5.5-7.0	Active
22	KB 25	PD000090	476552	673352	Loji Air Jelawat	6.441	52.9	75	51.4-52.9	Active
23	KB 26	PD000091	476552	673352	Loji Air Jelawat	6.442	33.5	75	32.0-33.5	Active
24	KB 28	PD000093	471731	674363	Loji Air Taman Guru (Pintu Geng)	6.066	71.5	75	70.0-71.5	Active
25	KB 29	PD000094	471733	674362	Loji Air Taman Guru (Pintu Geng)	6.083	59.5	75	58.0-59.5	Active
26	KB 30	PD000095	471743	674360	Loji Air Taman Guru (Pintu Geng)	6.01	10.5	75	9.0-10.5	Active
27	KB 49	PD000114	471792	674386	Loji Air Taman Guru (Pintu Geng)	7.44	14	100	5.0-14.0	Active
28	KB 31	PD000096	486188	671836	Pusat Kesihatan Beris Kubur Besar	3.386	107.5	75	106.0-107.5	Active
29	KB 32	PD000097	486190	671837	Pusat Kesihatan	3.601	95	75	93.5-	Active

No	Well ID	No HYDROdat	Easting	Northing	Location	Elevation (m)	Depth (m)	Diameter (mm)	Screen Depth	Status
					Beris Kubur Besar				95.0	
30	KB 33	PD000098	486188	671834	Pusat Kesihatan Beris Kubur Besar	3.332	77.5	75	76.0-77.5	Active
31	KB 34	PD000099	486189	671836	Pusat Kesihatan Beris Kubur Besar	3.341	39.8	75	38.3-39.8	Active
32	KB 35	PD000100	486190	671836	Pusat Kesihatan Beris Kubur Besar	3.388	25.5	75	24.0-25.5	Active
33	KB 36	PD000101	477214	665840	Pusat Kes. Peringat	5.872	35	75	33.5-35	Active
34	KB 37	PD000102	477203	674100	HUSM Kbg. Kerian	4.114	11.5	75	4.0-11.5	Active
35	KB 39	PD000104	478943	672145	Kg. Binjai (Amarda Tractor)	5.884	16	100	8.0-16.0	Active
36	KB 42	PD000107	474711	673407	Sek.Keb.Pasir Hor	6.179	10.5	100	3.5-10.5	Active
37	KB 43	PD000108	475126	670852	Sek.Keb.Seribon g	6.264	14.5	100	7.5-14.5	Active
38	KB 44	PD000109	476599	671137	Pasir Tumboh	5.669	14.3	100	4.5-14.3	Active
39	KB 45	PD000110	476453	672484	Kg. Chicha	6	11	100	3.0-11.0	Active
40	KB 51	PD000116	475894	678784	S.K.Rambutan Rendang	4.989	11.6	100	3.0-11.6	Active
41	KB 52	PD000291	477608	677561	Loji Air Kg. Teluk	4.914	19.8	100	3.0-19.8	Active
42	KB 53	PD000118	472048	675934	Kg. Puteh (Baru)	2.515	12.5	100	3.0-12.5	Active
43	KB 57	PD000122	468409	677020	Loji Air Wakaf Bharu	6.059	11.5	40	10.0-11.5	Active
44	KB 58	PD000123	484104	668209	Loji Air Kg Chap	4.284	24.5	40	22.0-24.5	Active
45	KB 89	PD000313	489250	648129	Bkt. Gedombak P. Puteh	N/A	N/A	75	N/A	Active
46	KB94	PD000326	459998	685283	Kg. Kok Bedullah	N/A	N/A	75	N/A	Active
47	KB95	PD000327	460212	685220	Kg. Kok Bedullah	N/A	N/A	75	N/A	Active
48	KB96	PD000328	460384	685175	Kg. Kok Bedullah	N/A	N/A	75	N/A	Active
49	KB97	PD000329	460699	685196	Kg. Kok Bedullah	N/A	N/A	75	N/A	Active
50	KB98	PD000330	460683	685062	Kg. Kok Bedullah	N/A	N/A	75	N/A	Active
51	KB99	PD000331	460721	684895	Kg. Kok Bedullah	N/A	N/A	75	N/A	Active
52	KB100	PD000332	460815	685161	Kg. Kok Bedullah	N/A	N/A	75	N/A	Active
53	KB101	PD000333	460682	685139	Kg. Kok Bedullah	N/A	N/A	75	N/A	Active
54	KB102	PD000334	456002	662419	Pusu 40 Rantau Panjang	N/A	N/A	75	N/A	Active
55	KB103	PD000335	455671	662411	Pusu 40 Rantau Panjang	N/A	N/A	75	N/A	Active
56	KB104	PD000336	455617	662216	Pusu 40 Rantau Panjang	N/A	N/A	75	N/A	Active
57	KB105	PD000337	455968	662266	Pusu 40 Rantau Panjang	N/A	N/A	75	N/A	Active
58	KB106	PD000338	455767	662421	Pusu 40 Rantau Panjang	N/A	N/A	75	N/A	Active
59	KB107	PD000339	455635	662308	Pusu 40 Rantau Panjang	N/A	N/A	75	N/A	Active
60	KB108	PD000340	455590	662302	Pusu 40 Rantau Panjang	N/A	N/A	75	N/A	Active

No	Well ID	No HYDROdat	Easting	Northing	Location	Elevation (m)	Depth (m)	Diameter (mm)	Screen Depth	Status
61	KB109	PD000341	455655	662124	Pusu 40 Rantau Panjang	N/A	N/A	75	N/A	Active
62	KB 61	N/A	477900	681700	Loji Air Pengkalan Chepa	5.8	4	75	2.5-4.0	IN/Active
63	KB 17	N/A	473300	678500	Tangki Air Jalan Merbau	6.596	85	75	83.5-85.0	In-active
64	KB 22	N/A	486700	664700	Loji Air Jelawat	3.614	47.5	75	46.0-47.5	In-active
65	KB 27	N/A	476300	673500	Loji Air Kubang Kerian	6.419	12	75	10.5-12.0	In-active
66	KB 38	N/A	477400	675800	Loji Air Kg. Kota	3.299	13.5	100	12.0-13.5	In-active
67	KB 40	N/A	480000	675900	Sek.Keb.Kedai Lalat	3.889	18.9	100	8.5-18.9	In-active
68	KB 41	N/A	474300	671500	Kg. Pdg. Penyadap	5.649	14.5	100	7.5-14.5	In-active
69	KB 46	N/A	473700	674100	Kg. Bunut Payong	3.77	5.4	100	3.0-5.4	In-active
70	KB 47	N/A	472300	673400	Wakaf Che Yeh	6.52	13.5	100	3.5-13.5	In-active
71	KB 54	N/A	471700	676600	Bawah Lembah	2	10.5	100	5.0-10.5	In-active
72	KB 55	N/A	470200	676800	S.K.Pasir Pekan	6.527	11.2	100	7.5-11.2	In-active
73	KB 56	N/A	465100	683400	Loji Air Kg. Sedar	4.636	31.5	40	30.0-31.5	In-active
74	KB 59	N/A	471900	676200	Loji Air Kg.Puteh	7.232	11.4	40	9.7-11.4	In-active
75	KB 60	N/A	471900	676200	Loji Air Kg.Puteh	6.936	13	40	11.5-13.0	In-active
76	KB 62	N/A	465400	673800	Bunut Susu	7.075	47.5	75	46.0-47.5	In-active
77	KB 63	N/A	465400	673800	Bunut Susu	7.025	30	75	28.5-30.0	In-active
78	KB 64	N/A	465400	673800	Bunut Susu	7.09	8	40	6.0-7.5	In-active
79	KB 69	N/A	474900	677400	Jln. Pekeliling (S.K. Islah)	4.255	9.5	40	8.0-9.5	In-active
80	KB 70	N/A	477100	673900	Tok Kenali, K.Kerian	3.97	34	100	32.5 - 34	In-active
81	KB 71	N/A	472800	659700	Loji Air Ketereh	N/A	41	200	27.0-31.0	In-active
82	KB 72	N/A	477800	656000	Loji Air Puspa Jaya	N/A	25	80	7.0-11.0	In-active

Table 4.3: List Of DOE's Monitoring Wells

No	Code	Well No.	Location	Category	Depth (m)	X	Y
1	D3A	MW(7)-D3-1-6.90	KELAB GOLF & DESA PKLN CHEPA	PADANG GOLF	6.9	479644.7	680612.0
2	D3B	MW(7)-D3-1-6.37	KELAB GOLF & DESA PKLN CHEPA	PADANG GOLF	6.37	479547.1	681165.1
3	D6-4A	MW(7)-D6-4-31.27	KELAB GOLF D'RAJA KUBANG KERIAN	PADANG GOLF	31.27	476743.7	672994.7
4	D6-4B	MW(7)-D6-4-4.47	KELAB GOLF D'RAJA KUBANG KERIAN	PADANG GOLF	4.47	476746.8	672985.5
5	D6-3A	MW(7)-D6-3-13.43	PANJI LANDFILL, PANJI, KOTA BHARU	TAPAK BUANGAN PEPEJAL	13.43	477904.7	678519.4
6	D6-3B	MW(7)-D6-3-5.34	PANJI LANDFILL, PANJI, KOTA BHARU	TAPAK BUANGAN PEPEJAL	5.34	477904.7	678516.3
7	D6-2A	MW(7)-D6-2-51.28	EASTERN GARMENT MFG., PKLN CHEPA	PERINDUSTRIAN	51.28	478954.7	679679.1
8	D6-2B	MW(7)-D6-2-4.24	EASTERN GARMENT MFG., PKLN CHEPA	PERINDUSTRIAN	4.24	478957.8	679697.6
9	D8-1A	MW(7)-D8-1-5.22	PASIR MAS LANDFILL, KG. PUSU 40, PASIR MAS	TAPAK BUANGAN PEPEJAL	5.22	455798.4	662268.2
10	D7-1A	MW(7)-D7-1-20.23	SEK. MEN. KEB. RANTAU PANJANG	PERBANDARAN	20.23	442627.6	665180.3
11	D7-1B	MW(7)-D7-1-6.10	SEK. MEN. KEB. RANTAU PANJANG	PERBANDARAN	6.1	442612.3	665214.1
12	D11-1A	MW(7)-D11-1-6.10	SEK. KEB. JELAWAT, BACHOK	LUAR BANDAR	6.1	486861.4	664790.9
13	D11-2A	MW(7)-D11-2-5.09	SEK. MEN. KEB. JELAWAT, BACHOK	LUAR BANDAR	5.09	486449.1	664644.0
14	D6-1A	MW(7)-D6-1-7.58	KAMPUNG JEMBAL, KOTA BHARU	PERTANIAN	7.58	482014.3	664428.9
15	D15A	MW(7)-D15-1-4.05	SEK. KEB. BERIS LALANG, BACHOK	PERTANIAN	4.05	491701.4	657249.2

Table 4.4: List Of NAHRIM's Monitoring Wells

No.	WELL NO	LOCATION	CROP	X	Y	Depth (m)	Diameter (m)	Screen
1	NW 33	KG. AMAN	AGRI (TABACOO)	495026	655013	25.0	100	3.0-7.0
2	NW 13	KG. PADANG TENGAH KETEREH	AGRI (PADDY)	470568	659077	25.0	100	3.0-7.0
3	NW 14	KG. SENENG JELAWAT	RESIDENTIAL	487552	663687	25.0	100	3.0-7.0
4	NW 19	KG. PENGKALAN NANGKA	RESIDENTIAL	476598	680668	25.0	100	2.0-4.0
5	NW 5	KG. KUBANG GOLOK	AGRI (VEG.)	487934	673948	25.0	100	11.0-14.0

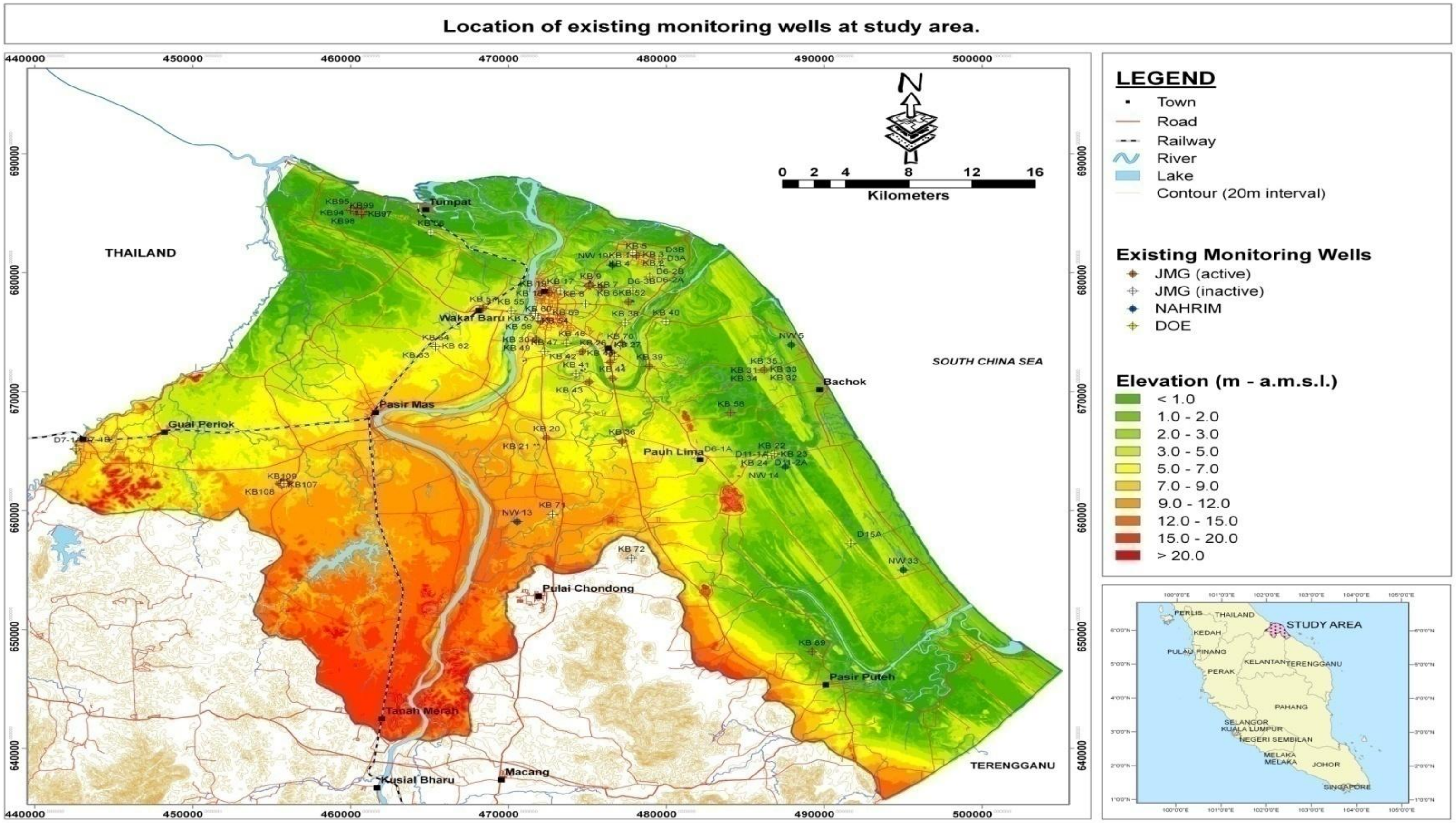

Figure 4.5: Existing JMG, DOE and NAHRIM monitoring well at the study area.

4.5.2 New Monitoring Well Location

In the new wells identification and network design, the combined hydrogeological information (existing and new) is used, where a new set of monitoring well locations would be identified across the study area. The selected network would be based on derived technical, environmental and cost criteria, classified as regional, local and at source levels.

Well network are planned in regional and local scale using spatial method, particularly across the North Kelantan alluvium, covering various landuse and polluting sources (point or nonpoint), soil group, recharge areas, multi-layered aquifers system and within groundwater catchment protection zone around the wellfields. The networks are designed such that water quantity and quality patterns could be assessed at different spatial scales.

Regional monitoring wells network are established based on two regional scale monitoring well networks, namely areal networks and transect networks. It is designed to provide a broad areal assessment of quantity and ambient water quality condition across the area. For the Areal Networks, the study area is to be systematically subdivided into polygons and then possible sites are chosen and identified as monitoring wells sites within each polygon, characterised by the types of landuse, soil and hydrogeology that overlay the geometric of each polygon concerned. For the Transect Network, the monitoring well sites are chosen from the transect lines drawn along, that stretches across the groundwater basins in easterly to westerly pattern. The transects lines are then spaced to provide a broad north-south bound coverage of the study area. It is very important that the representiveness of the well sites in this network is specifically applied, that targets the areas representing the different hydrogeomorphic regions along each transect lines.

This network is also applied for designing monitoring well distribution in priority areas such as in Kota Bharu Municipal Council (MPKB). The sites would also be chosen to investigate water quality variations in urban, industrial, residential, agricultural and natural areas in accordance with local shallow groundwater flow patterns using local areal network and transect network concepts. This higher network density area can be used for ambient and source monitoring.

This network is also be implemented in small area, in which probable point source of groundwater pollution exist, such as landfill and possible leaking sewage points. The outcome of the network would define the groundwater contaminant plume extent and geometry in the vicinity of the facility. The study has established the new locations of monitoring wells for groundwater monitoring network, as listed in Table 4.5 below.

Table 4.5: List and location of the proposed new groundwater monitoring network.

No.	Name	Location	X	Y	Note	No. of Monitoring well
1	M1	Kg Puteh Wellfield	472521.6	676126.1	Wellfield	4
2	M2	Pintu Geng Wellfield	471722.2	674361.4	Wellfield	3
3	M3	Kota Wellfield	471037.4	672670.4	Wellfield	3
4	M4	Pasir Hor Wellfield	474692	673217.3	Wellfield	3
5	M5	Penyadap Wellfield	474760.9	671859.2	Wellfield	3
6	M6	Seribong Wellfield	475164.9	670735.7	Wellfield	3
7	M7	Pasir Tumboh Wellfield	476764.5	670987.8	Wellfield	3
8	M8	Chicha Wellfield	477220.3	672273.5	Wellfield	3
9	M9	Kubang Kerian Wellfield	476648.9	673362.2	Wellfield	3
10	M10	Kenali Wellfield	477383	673945.3	Wellfield	3
11	M11	Tg Mas Wellfield	475143	678937.5	Wellfield	4
12	M12	Perol Wellfield	472426.1	666121.2	Wellfield	2
13	M13	Wakaf Bharu Wellfield	468384.9	677040.6	Wellfield	3
14	M14	Kg Chap Wellfield	484100.3	668211.4	Wellfield	4
15	M15	Pengkalan Chepa Wellfield	478093	681494.6	Wellfield	4
16	M16	Kg Teluk Wellfield	477687.9	677610.8	Wellfield	4
17	M17	Tangki Air Jalan Merbau	472549.7	678346.4	Urban	4
18	M18	Kota Bharu 1	473783.7	675469.7		3
19	M19	Kg Sireh (Nordin Batik)	471262.4	675105.4		3
20	M20	Loji Air Kelau	463005.4	665735.9		2
21	M21	Kota Bharu 2	474284.4	677574		3
22	M22	Kok Bedolah Landfill	460385.2	684926.5		4
23	M23	Sabak Landfill	480814.3	682900		4
24	M24	Danau Tok Uban	460096.8	656327.4		1
25	M25	Rantau Panjang	443103.1	665446.1		1
26	M26	Pasir Puteh	490179.9	645903.1		1
27	M27	Beris Kubor	486190.9	671823.9		4
28	M28	Caltex Kubang Kerian	477060.6	673306.4		3
29	M29	Batu 5 1/2, Jalan Kuala Kerai	472154.9	669850.6		3
30	M30	Danau Tok Uban (Downstream)	460932	659969.7		1
31	M31	Pantai Cahaya Bulan	474955.9	684155.6		4
32	M32	Kampung Laut	471417.4	683038.3		4
33	M33	Chabang Empat	463109.4	680329.8		3
34	M34	IKBN, Pasir Mas	456394.7	664133.9		2
35	M35	Bunut Susu	465327.2	674293.5		3
36	M36	Kampung Meranti	457431.8	674182.1		3
37	M37	Loji Air Jelawat	486857.1	664748		3

No.	Name	Location	X	Y	Note	No. of Monitoring well
38	M38	IKBN Bachok	490909.8	662530.9		4
39	M39	Semerak	494459.8	646728.2		1
40	M40	Melor	478411.8	660207.3		1
41	M41	Kampung Pulau Kapas	477243.6	675860.5		3
42	M42	Tok Jembal	481931.4	677581.2		4

In GIS format, the locations of the proposed new monitoring wells are shown in Fig.4.6, where the number of wells in each location has been identified. The wells recommended in the present study are single and multi penetration wells. Most of the proposed ambient monitoring wells are the single penetration type due to the insufficient information on the soil formation. Multi penetration monitoring wells are only proposed at sites where multi-layered aquifer is being identified. For the future construction of new monitoring wells will depend on changes in well designs, hydrogeological and groundwater quality monitoring requirements.

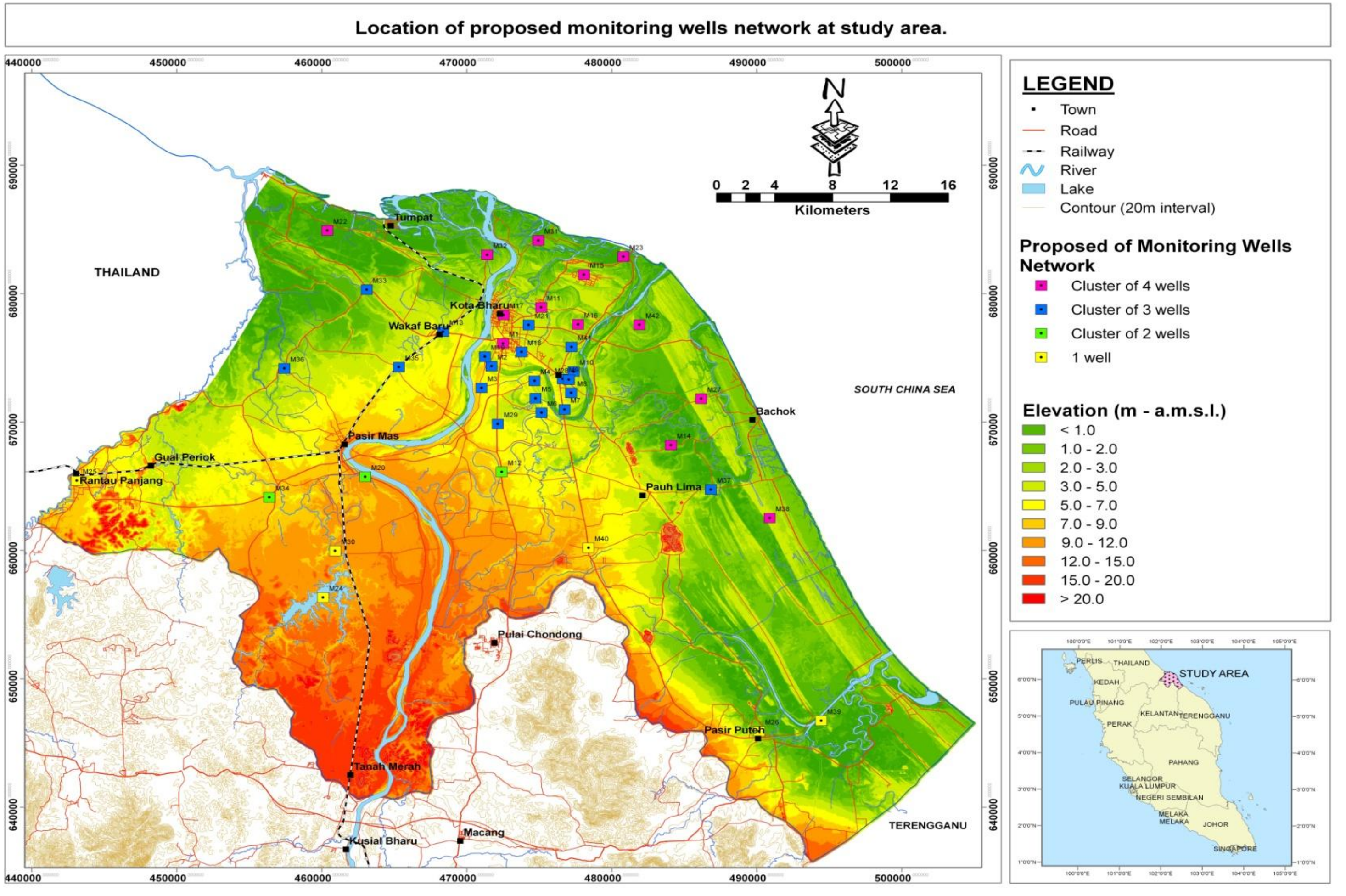

Figure 4.6: Location of the proposed new groundwater monitoring network

Briefly, the description of the wells to include, the well casing diameter of 4 inches (100 mm), the borehole diameter minimum of 4 to 6 inches (100 to 150 mm) larger than the well casing and the screen large enough in allowing proper placement of annular materials and accommodate minimum thickness of filter pack.

The well screens are to be placed in the layer for easy monitoring and be surrounded by coarser and higher hydraulic conductivity materials than natural formation material, for an efficient monitoring well design in unconsolidated geologic materials. The design allows undisturbed flow of groundwater into the well from the adjacent alluvium formation and also to minimise or eliminate the entrance of fine grained materials from the sand layer formation into the well.

Water samples are then collected and making sure of free of sediment to reduce the potential for sample interference. The length of well screen in the monitoring well is normally shorter than the production wells because it's used only to obtain water to monitor the conditions within an individual water-bearing unit. Whereas, for the production well design, a longer optimized length of the well is installed within an individual water-bearing zone, or in multiple water-bearing zones. For that some of the production well can be used as monitoring well.

A filter pack layer is installed in between the screen and the soil formation. The design of filter pack grain size and well screen slot size are determined by the grain-size distribution of the formation material. The filter pack acts as the principal hydraulic structure of the well and is designed to protection of the screens.

In monitoring wells design, the well screen are able to retain 90% to 100% of filter pack materials, because development is generally done after the well has been completed, and it is important to avoid excessive settling of the materials surrounding the well. To retain 99% to 100% of the filter pack, the well screen slot size equal to the D, size of the filter pack. To retain 90% of the filter pack use the D_{10} sizes. The typical monitoring well design is shown in Fig. 4.7 and the wellhead design is illustrated in Fig. 4.9.

This monitoring operation plan will establish further data collections in the groundwater level monitoring sequence that provides:

i. The rate of water level recovery at certain production rate;
ii. The groundwater drawdown limitation of production rate;
iii. The trending behavioural groundwater responding to external factors.

The groundwater level data collected is to be used in the integration with SCADA, GIS and the hydrogeological model coupled with other external data.

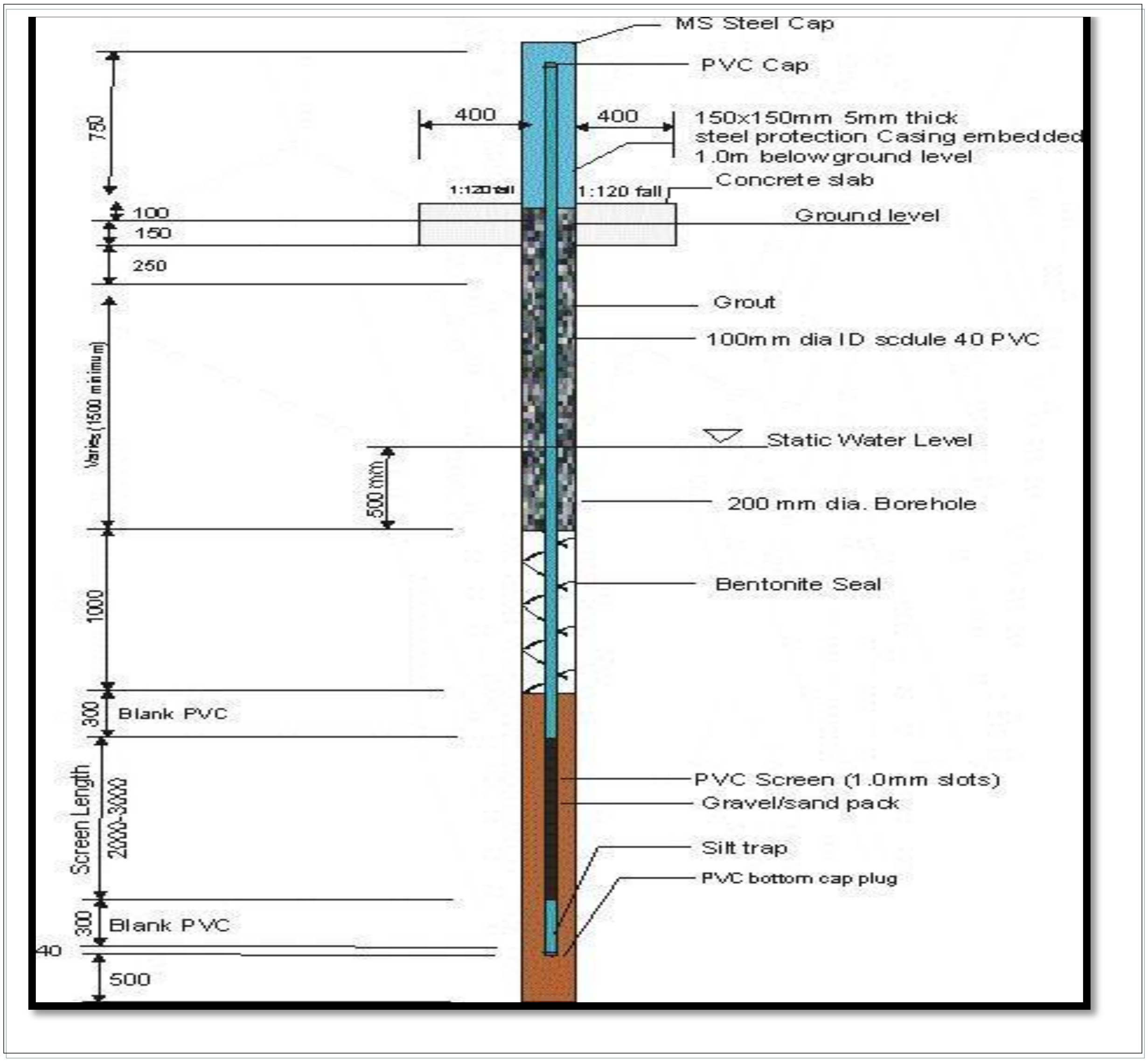

Figure 4.7: Typical monitoring well design.

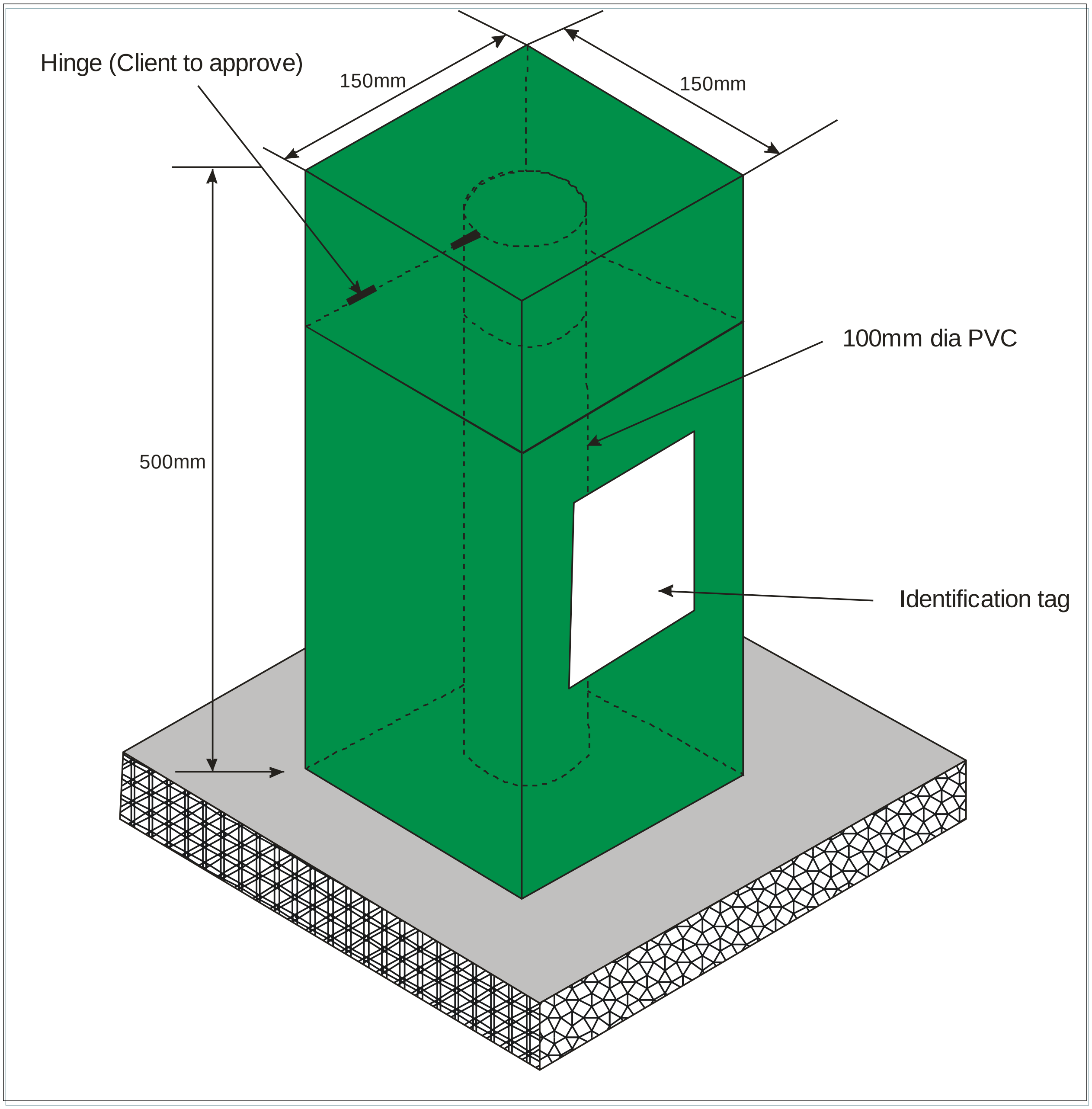

Figure 4.8: Wellhead design.

4.5.3 Groundwater Sampling and Analysis

The groundwater sampling forms the integral part of the groundwater monitoring system and as an identifying tool for regional and seasonal variation and long-term changes of groundwater quality of the study area. The results from the sampling provide the early indication of contamination problems exist in any area. The groundwater sample is designed to represent the particular zone of the water being sampled. The basis of interpretations of the quality of water is the chemical analysis in relation to source, geology, climate and its use.

Water samples are taken from the constant discharge pumping test sequence that provides information on water quality and its variability. The samples are taken during initial, middle and at the end of each pumping test.

The samples are then sent to laboratory further chemical analyses. The laboratory chemical test parameters are listed in Table 4.6. For on-site and in-situ analysis, the procedures are conducted at the site. The parameters for on-site analysis to include Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), manganese, iron, total iron, nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), phosphate (PO_4^-), water temperature, pH and conductivity.

Table 4.6: List of Parameters for Groundwater Quality Analysis

Category	Parameters to be Analysed
Physical	Temperature
	Turbidity
	Colour
	pH
	Conductivity
Inorganic	Dissolved Oxygen (DO)
	Biochemical Oxygen Demand (BOD)
	Chemical Oxygen Demand (COD)
	Manganese (Mn)
	Iron (Fe)
	Total Iron (Fe-T)
	Nitrate Nitrogen (NO_3-N)
	Nitrite Nitrogen (NO_2-N)
	Total Dissolved Solids (TDS)
	Total Solids (TS)
	Chloride (Cl)
	Anionic Detergent MBAS
	Ammoniacal Nitrogen (NH_3-N)
	Fluoride (F)
	Carbonate (CO_3)
	Hydrogen Carbonate (HCO_3)
	Total Hardness ($CaCO_3$)
	Sodium (Na)
	Calcium (Ca)
	Potassium (K)
	Aluminium (Al)

Heavy metals and others	Magnesium (Mg)
	Mercury (Hg)
	Cadmium (Cd)
	Selenium (Se)
	Arsenic (As)
	Cyanide (CN)
	Lead (Pb)
	Chromium (Cr)
	Silver (Ag)
	Copper (Cu)
	Zinc (Zn)
	Sulphate (SO_4)
	Silica (SiO_2)
	Phosphorus (P)
	Oil & Grease
	Phenol
	Chloroform

Category	Parameters to be Analysed
Biocides and others	Organochlorine Pesticides
	Organophosphorus Pesticides
	BTEX
	VOC (Volatile Organic Compounds)
	SVOC (Semivolatile Organic Compounds)
	Total Petroleum Hydrocarbon (TPH)
Microbiology	Total Coliform Bacteria
	E. Coli (Escherichia Coli)

4.6 RAINGAUGE AND STICKGAUGE ESTABLISHMENT PLAN

4.6.1 Surface Water Monitoring

To establish excellent hydrogeological models in the groundwater management operation and decision, establishment of aquifer interaction with surface water bodies is of principal importance. External factors such as rain fall, river flow, canal and lake outflows must be monitored so as to gather information as an input to the system and model. Thus monitoring rainfall/rainfall infiltration and river, lake and canal water levels are monitored, particularly within the study area bounded by the Kelantan River and Mulong/Pengkalan Datu River where extensive wellfields are located. Adjacent external systems that might have an effect on the study area are also monitored. River flows can be determined by installations of stick gauges and rain falls are observed by rain gauges installations.

4.6.2 Stick Gauges and Rain gauges

Selection of stick gauge locations is determined by factors such as stagnant water body and at defined intervals along moving and gradient waters. For rain gauges the existing facilities provided by Meteorological Department can provide sufficient information in the study area. Both gauges would be tied to SCADA system and their readings would serve as boundary condition (BC) for groundwater model elements. The list of proposed locations of stick gauges are shown in Table

4.7, alongside with the existing stick gauges. Further illustration in GIS map of the locations of the existing and proposed stick gauges are shown in Fig. 4.9.

Table 4.7: List and location of the existing and proposed stick gauges.

No.	Station No.	Station Location	YEAR OPEN	YEAR CLOSED	OWNER	Latitude	Longitude
1	5621401	Sg. Sokor di Kg. Tegawan	01/83		JPS	102.1014	5.629167
2	5721442	Sg. Kelantan di Jambatan. Guillemard/Kusial	1949		JPS	102.15	5.7625
3	5824401	Sg. Semerak di Pasir Puteh			JPS	102.4944	5.859722
4	6019411	Sg. Golok di Rantau Panjang	1938		JPS	101.975	6.0225
5	6021401	Sg. Lemal At Jambatan Repek	01/81	08/93	JPS	102.1028	6.013889
6	6022421	Sg. Kemasin At Peringat	10/61	01/92	JPS	102.2861	6.030556
7	6120401	Sg. Golok di Kuala Jambu	06/81	08/91	JPS	102.0958	6.163889
8	6122441	Sg. Kelantan di Jeti Kastam	12/62		JPS	102.2333	6.133333
9		Sg. Golok di Janob			New	101.8904	5.84217
10	DSG-1	Sg. Kelantan At Jambatan Wakaf Bharu			New	102.23	6.116932
11	DSG-2	Sg. Kelantan At Jambatan Tendong			New	102.2146	6.056694
12	DSG-3	Sg. Kelantan At Jambatan Pasir Mas			New	102.1474	6.032392
13	DSG-4	Sg. Pengkalan Datu at Pasir Tumboh			New	102.2813	6.061033
14	DSG-5	Sg. Pengkalan Datu at Pulau Melaka			New	102.2979	6.117385
15	DSG-6	Danau Tok Uban			New	102.131	5.934887
16	DSG-7	Sg. Golok			New	102.0567	6.080916

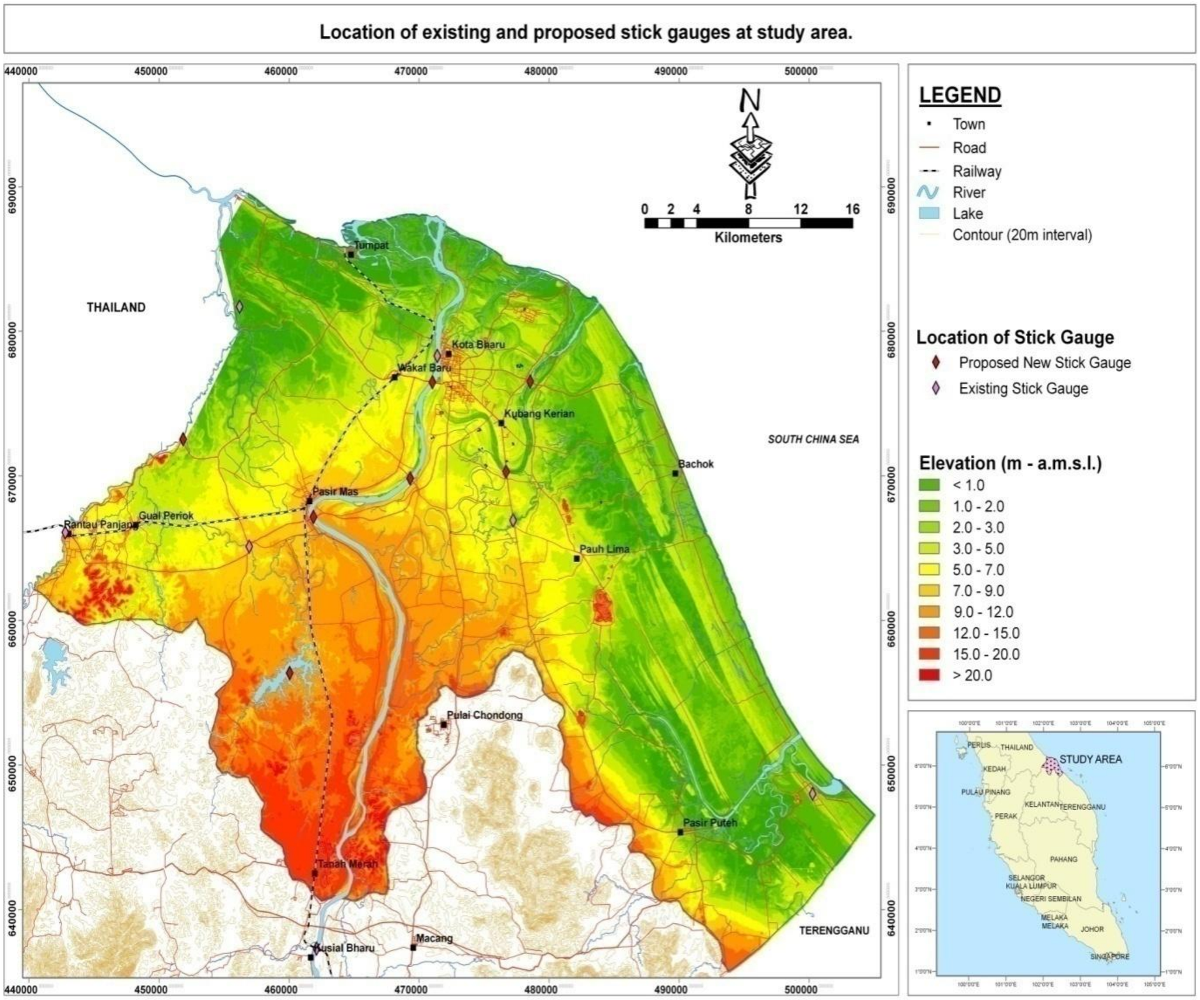

Figure 4.9: Location of existing and proposed river stick gauge.

The important data required to perform the necessary analyses of well network design are hydrogeological classification and groundwater usage, landuse/landcover and polluting source areas, surface soil infiltration, and topographic map. The final network plan can be finalise with further refinement when the updated data processing and geophysical survey is completed in the near future.

4.7 SCADA SYSTEM ESTABLISHMENT PLAN

4.7.1 Systems concepts

The term SCADA usually refers to centralized systems which monitor and control entire sites, or complexes of systems spread out over large areas. An effective wireless monitoring system can be installed, to assist water management companies, with relatively low capital investment. This wireless monitoring system provides:

i. Relatively low technical manpower and less expensive human capital requirement.
ii. Relatively low cost of equipments and monitoring tools.
iii. Effective standard operating procedures.
iv. Consistently monitoring and providing real time data with low marginal error.
v. Historical data and trends for future water management studies and planning.

Most control actions are performed automatically by Remote Terminal Units (RTU) or by programmable logic controllers (PLC). Host control functions are usually restricted to basic overriding or *supervisory* level intervention. Data acquisition starts at the RTU or PLC level and includes meter readings and equipment status reports that are communicated to SCADA as required. Data is then compiled and formatted to make supervisory decisions operators easy to adjust or override normal RTU (PLC) controls.

SCADA implementations require the setup of its alarm handling. The system will monitors where certain alarm conditions are met, to determine when a predetermine event has occurred. Once an alarm event has been detected, one or more actions are taken (such as the activation of one or more alarm indicators, and perhaps the generation of email or text messages so that management or remote SCADA operators are informed). Alarm conditions is an over-the-limit point where a digital status point that has either the value normal or alarm that is calculated by a formula based on the values in other analogue and at these digital points, the SCADA system will automatically monitor whether the value in an analogue point lies outside high and low limit values associated with that point.

4.7.2 Current SCADA system

There are many SCADA technologies that have been implemented for different purposes and usage but it is important for users to define their main objective and future requirement as to determine the potential scalability and extensions of functions. These are the most important and critical success factor of SCADA system to be considered which were:

i. Backhaul and protocol for hardware interchange ability.

ii. System language and database programming.

iii. Power management system.

AKSB has already installed the SCADA system using hot-wired and wireless GSM backhaul in its water production plants. The system is a comprehensive water production system that controls the overall operation of water treatment processes that include the opening of valves and running water pumps, by either manually or on a parameter control setting. Without proper planning and appropriate technology transfer, the system installed are unable to perform to it’s specified requirement. This is due to:

i. No proper planning on hardware preventive maintenance on replacement of parts within certain period of time as critical system function.

ii. Minimum technical support since the system is not locally developed and no proper technology transfer and product training by technology provider. Continuous on job training and appointment of management trainees will ensure the continuity of technological advancement in SCADA system.

iii. Being a closed system that does not allow any integration with other software or hardware. It is advisable that software selection must consider the scalability of the database where programming source codes have to be transferred to user for future usage.

iv. The GSM backhaul used is expensive in long run, unless the system is for temporary usage such as periodical study. Short term monitoring GSM is best suit the system. For continuous all year round monitoring and multiple sensory devices function and execution control, it is advisable to use a permanent data transfer and monitoring backhaul such as Wife or UHF communication backhaul.

v. The installation of hardware from various models and brands unable to communicate with the HMI system. By designing an open system with access protocol interface (API) system application and the appropriate selection of HMI with database system, it is able to integrate with various models and brand that come with API.

Some of the water treatment plants are located in remote places and for the purpose of ground water monitoring system installations and workability of the monitoring system, therefore the possible base requirement that are to be considered:

i. It must be an open database system for it to enable hardware from various brands and model can communicate with the HMI system;

ii. Installed with permanent communicate backhaul with minimum monthly subscription fees such as Internet WiFi or UHF communication system, which is the best option for the ground water monitoring system since there are multiple monitoring well within a specified compound;

iii. Ability for hardware installations to integrate with any communication system without having expensive hardware or gadgets and costs less maintenance;

iv. The hardware installation must have safety aspect of the hardware where sufficient protection against external element to prevent disruption or damage the hardware itself; and

v. Automatically, the hardware must be able to transfer the information without human interference.

The functions of ground water monitoring system are designed to:

i. Automatically gather continuous water level data at production wells in operation;
ii. Be able to provide graphical and summary reports, water level historical data and also record the data collected manually; and
iii. Wireless, easy and friendly access to ground water level data and its reports anytime, anywhere through web base applications.

4.7.3 Proposed SCADA system in GWRM

The SCADA System proposed for the GWRM system shall be crucial to the safe operation of the current and future water production wells for AKSB. The SCADA System allows the water manager to:

i. Monitoring functions:
   - The effect of ground water level in regards to raw water production;
   - The peak performance of water level recovery in order to maximize the capacity of the ground water without affecting the ground water volume; and
   - The ground water production volume to ensure the continuity of water supply as the depletion rate.

ii. Recording function:

- Fluctuation of the ground water level in natural climatic variation;
- Fluctuation in river, canal and lakes for surface water; and
- Rain water or precipitation rate.

iii. Study and analysis functions:

- Analyse the water level behaviour and interdependency with rain intensity, river surface level and surface level of water catchment area such as lake;
- Correlate between these 3 above factors to provide a better understanding on the ground water recovery rate as the catchment area in terms of provision of raw water supply to the production well; and
- Study the effect and relation between water contamination and ground water level. As the water production increased, the will be some depletion of ground water level.

To ensure the stability of communication backhaul with the data continuously retrieved from the production sites, the web base application system is used for data retrieval and processes with status reporting via the internet. The database is connected to the main database in real time via production site data collection server connected to the central database via wireless backhaul either UHF antenna or Wi-Fi Mesh network. For monitoring wells application with more than 1 ground water level sensor, the system network proposed as illustrated in Fig. 4.10.

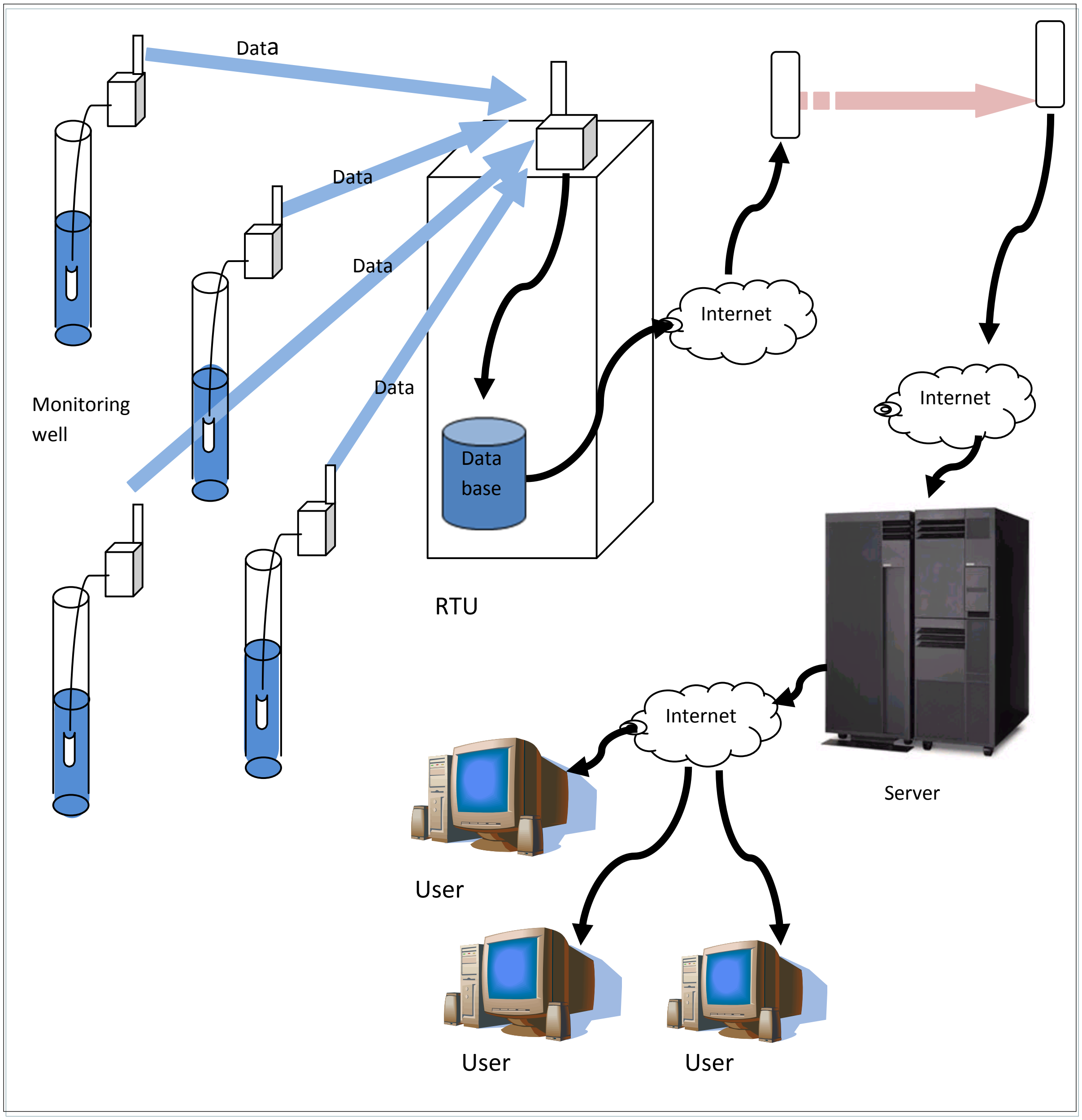

Figure 4.10: System Architecture Topology for SCADA System

For monitoring well with only 1 ground level sensor, a GSM system which is less expensive setup of system network, as illustrated in Fig. 4.11.

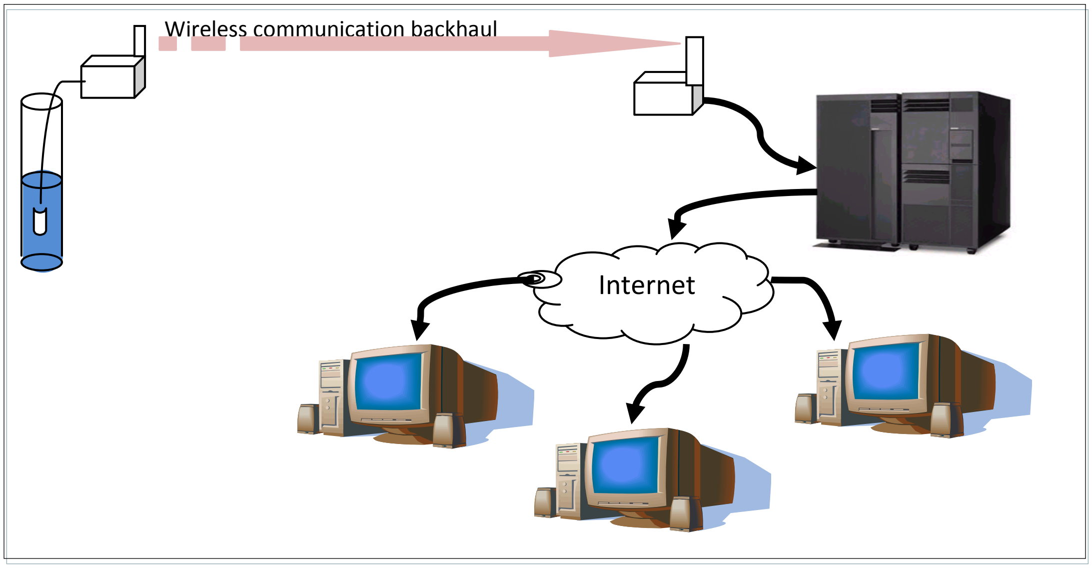

Figure 4.11: Wireless System Topology Backhaul for SCADA System.

The hardware consists of RTU and water level sensor which send the water level readings in 3 domain catogery:

i. Time interval,

ii. Water level.

iii. Time interval and water level.

The Human-Machine Interface (HMI) is a medium of interaction between human and the sensor devices in data and reporting language. This HMI-system software combination is based on web base application system that combines data storage and data management system via Internet. The system can be divided into 3 main system components, namely:

i. Client server system application:

- Multiple remote sensor data collection system from within the specified area and identification tag. The client server system will be installed with hardware system enabler within a specified distance depending on the communication protocol either RFID, USB, TCPIP, RS232 or others.

- Minimal data storage before transferring it to the server. The system will store the data reading with in specific time or size so that when the data failed to be transferred automatically, it is still available to manual transfer.
- Updating the sensor status, power supply status and the communication signal status and updating it into the server. The client server system will open data transfer channel in specified time so that real time data information can be updated into the system server without having it to become prone to hacking.
- Client server browser will enable registered personnel via login ID and password to access the information on the monitoring site via public IP.

ii. Web server system application:

- Data base management system where every client server from each site will share their data through automatic push and pull data in one fixed format.
- The web server can also browse the entire client server and do manual data extraction in case of communication network broken.
- The server will provide a mirror database as a backup for the entire system and details records on every user activity.

- The server software has interface panel of each monitoring well that can be projected in real time records where the additional information such as water quality, water level, production rate, production volume and other information can be written and recorded into the database. The interface panel will also retrieve data, statistic and also graphical reports on each criterion versus any of the criteria.

Several site visit has been conducted and a number of well has been identified. All existing and new proposed production wells and monitoring wells are to be fitted and connected with the Wireless SCADA System. The SCADA software and hardware are then able to take effective remedial action that could guaranteed the safety of the public's drinking water.

4.8 GROUNDWATER MONITORING OPERATION PLAN

Groundwater monitoring provides data on groundwater quality and quantity and is an integral aspect of groundwater management. Continual monitoring of groundwater assesses the impact of human activities on groundwater systems. Ideally groundwater monitoring should be carried out regularly in all areas where groundwater resources are extracted for a variety of uses.

4.8.1 Groundwater Monitoring Objectives

The main objectives of groundwater monitoring are:

i. To collect data documenting any change in groundwater storage over time

ii. To provide both long-term and short-term data necessary to assess and predict the response of hydrologic systems to natural climatic variations and human-induced stresses

iii. To establish as accurately as possible the baseline quality of groundwater occurring naturally in aquifers

iv. To detect trends in the concentrations of these groundwater constituents, this may pose a risk to human health or impact on other human activities.

Groundwater monitoring systems must consist, at a minimum, of an adequate number of wells installed into the aquifers to yield samples that comprise of:-

a) Groundwater level monitoring

The principle purposes of groundwater level monitoring are to provide data about groundwater system behaviour and overall impacts on the groundwater situation caused by groundwater exploitation and other interventions. Groundwater levels are affected by natural climatic conditions (amount of recharge reaching the aquifer) as well as by a range of human activities, such as land use and groundwater extraction. It is of vital importance to monitor changes in the water level within the aquifers as it helps to manage the groundwater resources properly and plan land use activities to minimize their impact on the environment. Seasonal and yearly changes in groundwater levels are represented in a hydrograph.

Frequent (monthly or even weekly) and regular groundwater level monitoring reveals important elements such as:

- The groundwater depth;
- The groundwater rising or falling over time;
- The effect of irrigation or other management practices have on water table movement;
- The magnitude of effect of rain events on the water table;
- The time effects of a rain event on the water table; and
- The effect of a prolonged dry spell on the water table.

Data collected over long periods (years) can provide information on long-term effects of the climate and extraction levels on the aquifer.

b) Groundwater quality monitoring

Groundwater quality monitoring networks provide information on the chemical status of groundwater systems and the effects on groundwater quality and establish the presence of any significant upward trend in pollutant concentrations and the reversal of such trends. Groundwater quality monitoring can be done for the purposes of:-

- To understand the current state of water quality in the aquifer
- To check compliance with standards
- To detect long-term trends in groundwater quality
- To determine suitability for specific uses
- To understand the causes of salinity
- To detect suspected contamination
- To prevent and/or remediation of saltwater intrusion in coastal aquifers
- To trace movement of contamination within the aquifer.

Depending on the purpose of the monitoring, a variety of parameters can be tested. Comprehensive chemical analysis of groundwater involves specific sampling protocols for different water constituents and contaminants and some analyses can be done only in a laboratory, as specialised equipment is necessary. Often only certain parameters pertaining to a specific problem are tested.

Electrical conductivity (EC) is one of the most important and commonly measured parameters. It provides information on the salt content (salinity) of groundwater. Seawater intrusion, the most common pollutant of fresh groundwater, is a growing problem in areas where coastal aquifers are used as a source of drinking water for growing populations of coastal communities. As little as 2% seawater in freshwater can render the water not potable. The salinity of the groundwater also determines its uses in agriculture and industry. Long-term salinity monitoring helps identify and possibly prevent and/or remedy problems of groundwater salinity.

c) Monitoring groundwater discharge and abstraction

Data on the amount of groundwater discharged from the groundwater system through different manners (springs, wells, etc.) is indispensable information for groundwater resources assessment and in particular for estimates of the potential of the system for water supply. Daily volume of groundwater abstraction is necessary to be collected.

At present, the volume of groundwater abstraction for individual production wells is monitored at only at Kg. Puteh wellfield. The rest of the wellfield, only the total estimation of the abstraction from the wellfields was recorded.

d) Monitoring seawater intrusion

Seawater intrusion occurs when natural discharge and abstraction of groundwater in a coastal zone exceed average groundwater recharge and inflow. The key to controlling this problem is to maintain the proper balance between water being pumped from the aquifer and the amount of water recharging it. Constant monitoring of the seawater interface is necessary in determining proper control measures.

e) Land Subsidence

The land subsidence measurement is an important monitoring for the groundwater environment because land subsidence is one of the negative impacts caused by groundwater over extraction. The previously installed land subsidence measurement network at the locations shown in Table 4.8 and the Figure 4.12 and the monitoring work should be conducted regularly.

Table 4.8: List of Land Subsidence monitoring location.

Bil	Location	Type	X	Y	Elevation
1	Wakaf Bharu	Benchmark	468423.7	677043.1	5.155
2	Wakaf Bharu	TBM	468483.7	677037.1	N/A
3	Wakaf Bharu	TBM	468404.7	677015.1	N/A
4	Wakaf Bharu	TBM	468454.7	676980.1	N/A
5	Kenali	Benchmark	477399	673992	7.713
6	Kenali	TBM	477300	674075	N/A
7	Kenali	TBM	477324	674011	N/A
8	Kenali	TBM	477435	673909	N/A
9	Pasir Hor	Benchmark	474626	673138	3.843
10	Pasir Hor	TBM	474635	673113	N/A
11	Pasir Hor	TBM	474670	673197	N/A
12	Pasir Hor	TBM	474719	673239	N/A
13	Pintu Geng	Benchmark	471758	674359	5.724
14	Pintu Geng	TBM	471777	674362	N/A
15	Pintu Geng	TBM	471800	674405	N/A
16	Pintu Geng	TBM	471708	674396	N/A

Figure 4.12: Location of the existing land subsidence monitoring datum.

4.8.2 Management Concept

The management of the complete groundwater resource management system uses the groundwater model, whereby the amount of infiltration water from the source, i.e. Kelantan River and surface runoff, is calculated from the observed flow from the sources. This model is further employed to control the groundwater flow in the management area. In Fig. 4.13, summarizes the flow processes of groundwater monitoring concept in GWRM system.

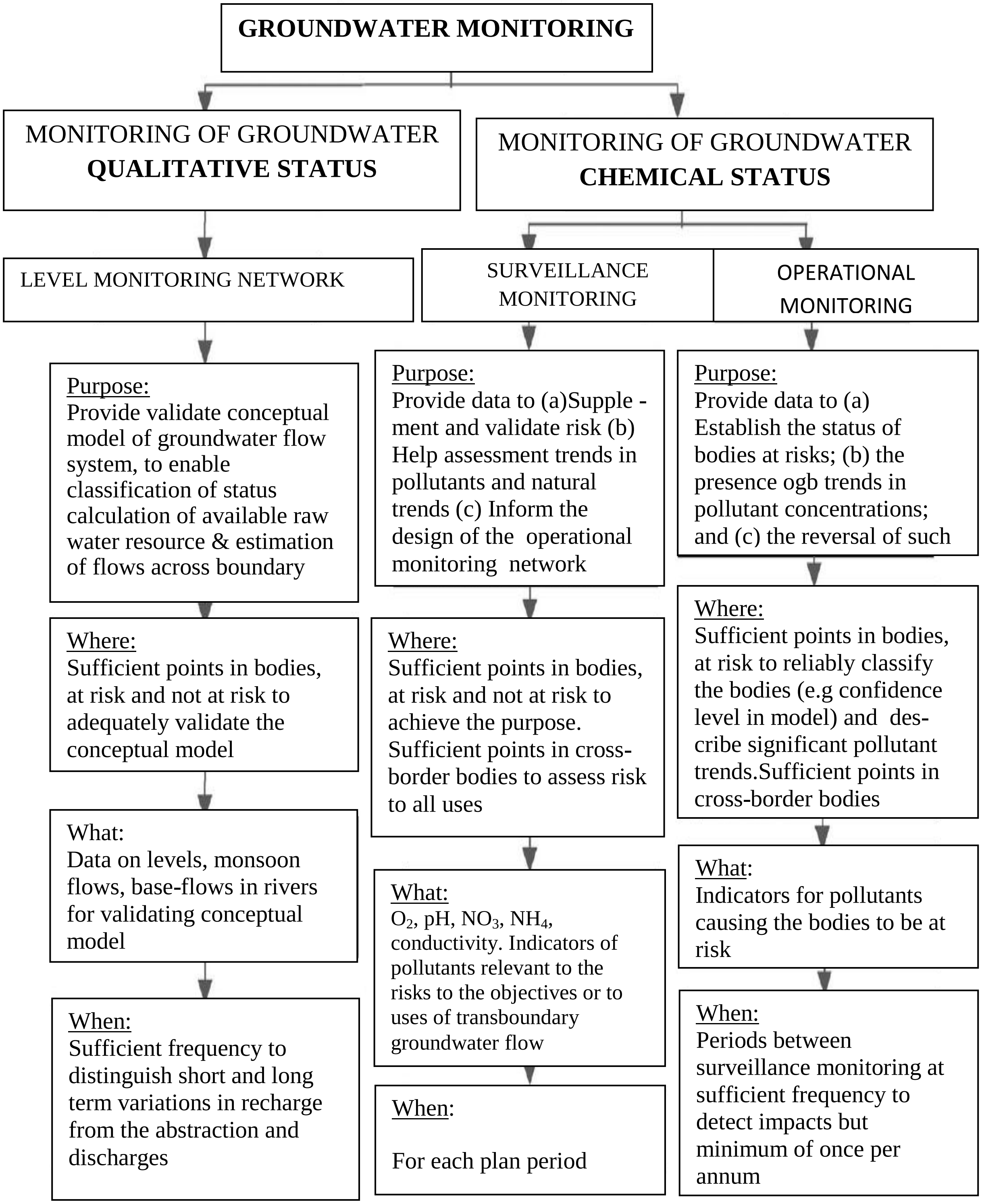

Figure 4.13: Summary of groundwater monitoring system.

4.9 CREATION AND CALIBRATION OF HYDROGEOLOGICAL MODELS

4.9.1 Introduction

A major concern in Malaysia in recent years is the development of water management policies. The groundwater usage and preservation of ecosystem are not being monitored enough. This brings much anxiety to the Government and public alike, recognizing the future potential of groundwater as an important source of water for the country.

One of the main tasks under the present study is the creation and calibration of groundwater model. Models are tools that often used during the investigations of groundwater resources and abstraction of an area. Models are also commonly used in investigation of water abstraction in connection with groundwater contamination and stream flow depletion. The data obtained from the existing setup and collected from the surveys carried out will be evaluated and optimally interpreted. The results from the interpretation are usually presented in relation with the geographical location, using tools like GIS software to achieve the purposes. The model will address the needs of existing and future management of groundwater in Kelantan by proposing affordable short-term and long-term development plan for the groundwater monitoring in the new and existing wells within the study area, consistent with the Government, other stakeholders and community expectations.

In this scope of the study, the creation and calibration of flow model is critical and entails the very importance of this exercise in the whole study. Nevertheless, the large of area of northern Kelantan limits the effort to create such a comprehensive model in this study. To the order of good representation for the whole study area, it is decided that the creation and calibration the flow model to be concentrated in a Pilot Project Area (Figure 4.18) which involved the followings:

i. Construction of the Hydrogeological Conceptual Model
ii. Construction, Run, Calibration and Validation of flow model of multilayered aquifer using MODFLOW Software for transient flow. Output of the modelling work shall consists:
    - Water balanced of the modelled area
    - Sustainable amount of groundwater for development
    - Delineation of the flow direction to well-field and well-field capture zones
iii. Simulation of few scenarios to ascertain future conditions.

The proposed groundwater model will provide the AKSB and other interested parties a critical management tool. The model will be used to test out possible future scenarios of groundwater use and how they would impact water levels for other neighboring users. It would help to ascertain whether there would be a need to lower pumps, re-drill wells, or in extreme cases even draw water from another aquifer. AKSB And Geological Survey staffs could modify the current model as needed to test various scenarios of concern. These scenarios could involve a point demand such as how will a major industry such as a textiles impact this resource if additional demand is placed on the North Kelantan, or how would the aquifer be impacted if a major industry converts from using groundwater to surface water as a source water to meet its needs.

Other scenarios could involve how changes in agricultural demand could impact the Kelantan aquifer, the spreading out of community demands through different configurations of supply wells, or even impacts of global warming and associated possible climate change on recharge rates and ultimately supply within the Kelantan Aquifer. Thus, this management tool can be use to foreworn communities of possible impacts on neighbours from the impact of major new groundwater users hence allowing for accommodations prior to impacts and thus avoiding costly laws suits as communities are surprised by impacts that were not expected.

4.9.2 Transient State Groundwater Modelling

4.9.2.1 Introduction

In this chapter, the transient state groundwater modelling is discussed. The discussions focus on the background to transient model simulation and its parameterizations. The model calibration as well as the sensitivity analysis with the model are also discussed. A calibrated transient model has been proposed and validated. The model has been used to assist the design and installation of the horizontal well and horizontal well collector.

4.9.2.2 Background to Transient State Modelling

Transient simulations are needed to analyse time-dependent problem and typically begins with steady state initial conditions (Anderson and Woessner, 1992). The transient modelling is more complicated as the storage properties and starting head must be defined. The time dimension must also be discritized and the hydrologic stresses may propagate to boundaries. The objective of transient simulation is generally to predict head distributions at successive times, given the initial head distribution, the boundary conditions, the hydraulic parameters and external stresses (McDonald and Harbaugh, 1988).

In this modelling study, the transient modelling has been carried out since the model can be used to evaluate the transient effect of recharge on groundwater resource and future planning of plant development. This can be done by assigning the different recharge inputs estimated from the average monthly rainfall and examine the change in hydrogeological conditions such as water levels. It is assumed that the stress imposed on the system will not propagate to the boundary.

The period for the transient simulations of the area is from 2000 to 2005. The aims of the transient modelling is to reproduce field water level hydrographs (monthly basis) for a few selected boreholes in the catchments.

There are some special needs for transient simulations as described by Anderson and Woessner (1992) are discussed below;

i) Storage Parameters

In this modelling study, the confining layer which is the silty clay has also been modelled, so the layer should also be assigned the storage parameter which is specific yield (Sy) in this case.

ii) Stress Period and Time Step

In transient modelling, the simulation time is divided into stress periods, the time intervals during simulation which all the external stresses are constant. In turn, a stress period is divided into time steps (McDonald and Harbaugh, 1988). Modflow groundwater model allows the use of stress periods which may have variable length. The use of stress periods offer the option of changing some of the parameters or stresses while the simulation is on progress. Modflow also use a time step multiplier which may be reset at the beginning of each stress period with a new time step. Selection of the time step in transient simulation is critical steps in model design because the value of time discretezation strongly influence the numerical results. Space discretezation also has a strong influence on numerical analysis.

For this transient state modelling, each month from 2009 to 2010 will be treated as one stress period with pumping stresses remain unchanged.

This modelling study also assumed that the water abstractions for each stress period remain the same and would not have any effect on model solution. A reason which leads to this assumption was that the monthly abstraction data is not available. It is also assumed that the steady state boundary conditions would not affect model solution.

4.9.2.3 Groundwater Modeling

i. Modelled area

The area to be modelled for this project is shown in Figure 4.14. The regional conceptual model was developed for the area with few assumptions on the aquifer layers and hydraulic properties. The model was calibrated and validated against the measured field data on water levels.

ii. Conceptual Model

A conceptual model is a pectoral representation of the groundwater flow system, frequently in the form of a block diagram or a cross section (Anderson and Woessner, 1992). For the present study, there are few available conceptual models of the aquifer system that can be found in Saim (1996) and Faizal (2002). The generalized stratigraphic unit for north Kelantan aquifer is shown in Figure 4.15. The whole aquifer system may consist of few aquifer layers. As for the horizontal well installation, the proposed model only models the first layer aquifer. The confining layer of silty clay above the first layer sand aquifer is also being modeled. The aquifer parameters and sources are given in Table 4.9.

Two hydrostratigraphic layers were defined at the site based on data collected from previous studies (DMG, Saim 1997; Mohamad Faizal 2002). The top layer was defined as about 5m silty clay layer, followed by a coarse sand layer that may reach 15m thick. The conceptual model of North Kelantan aquifer is shown in Fig.4.16.

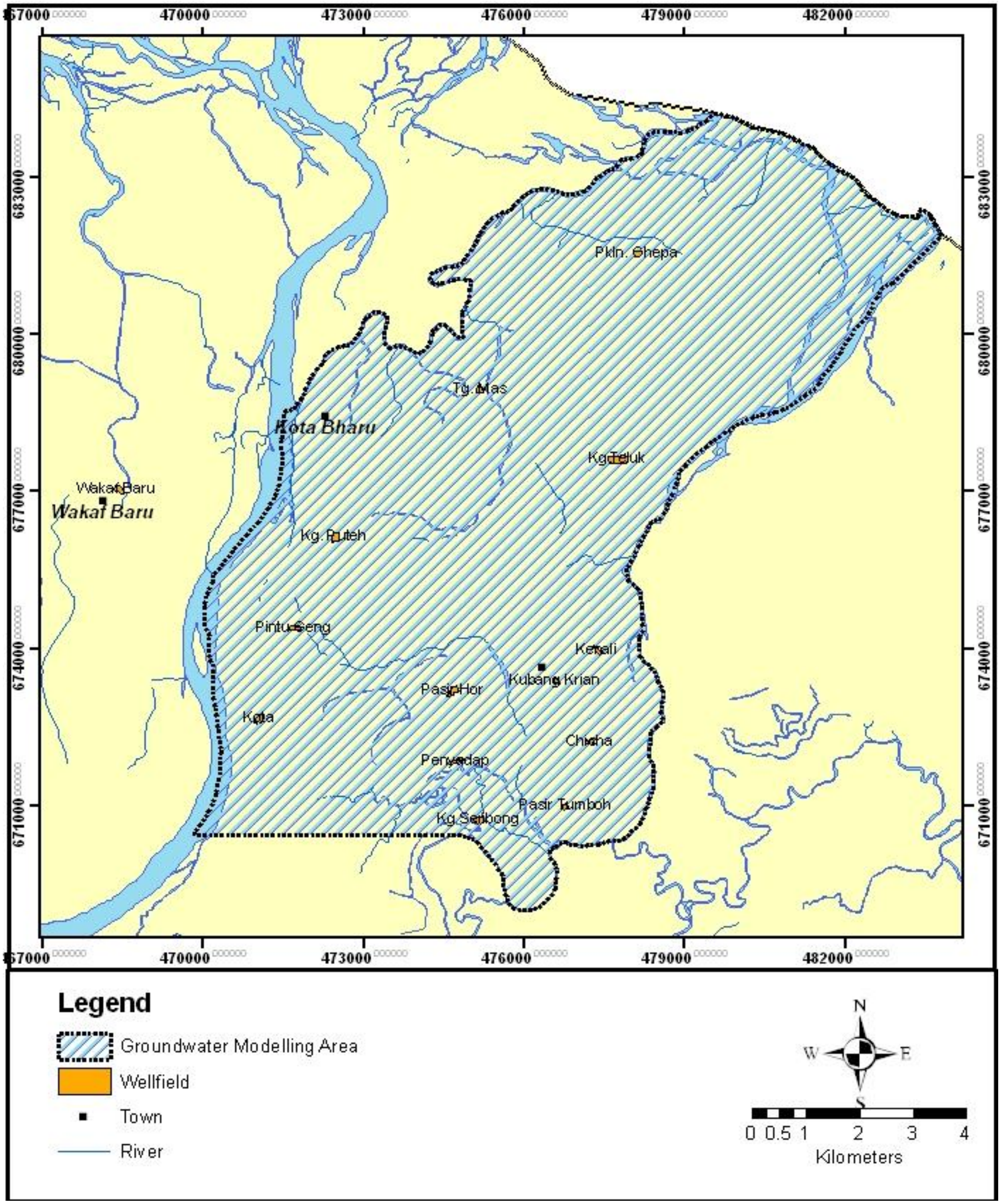

Figure 4.14: Proposed coverage of North Kelantan groundwater model.

Table 4.9 : Model Parameters and Sources

Item	Parameter	Source
1	*Model boundaries* Northern and Eastern boundary Western boundary Southern boundary	Saim (1997) and Mohamad Faizal (2002) Geology, hydrogeology map, JMG reports
2	Model layer	Saim (1997) and Mohamad Faizal (2002) Borehole information, JMG report
3	Aquifer Thickness and bottom elevation	Borehole information, JMG report Saim (1997) and Mohamad Faizal (2002)
4	Aquifer hydraulic conductivity	Saim (1997) and Mohamad Faizal (2002) JMG reports, established value,
5	Recharge	Estimation from Rainfall data (Jan 2000 – Dec 2005) & (Jan2009 – Dec 2010)
6	Water abstraction	Air Kelantan Sdn. Bhd. JMG records
7	Groundwater level	JMG records

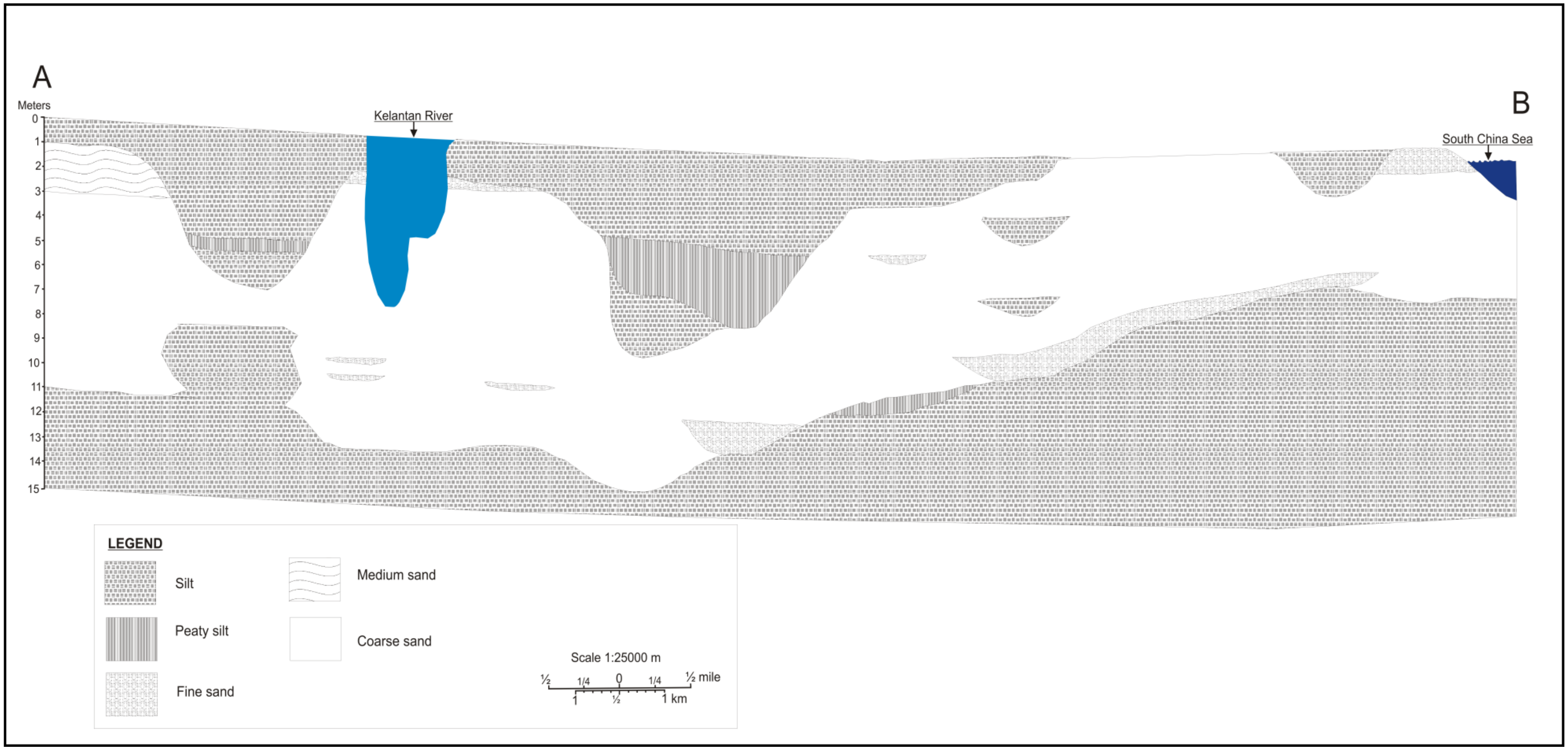

Figure 4.15: Generalized hydrostratigraphy of North Kelantan aquifer

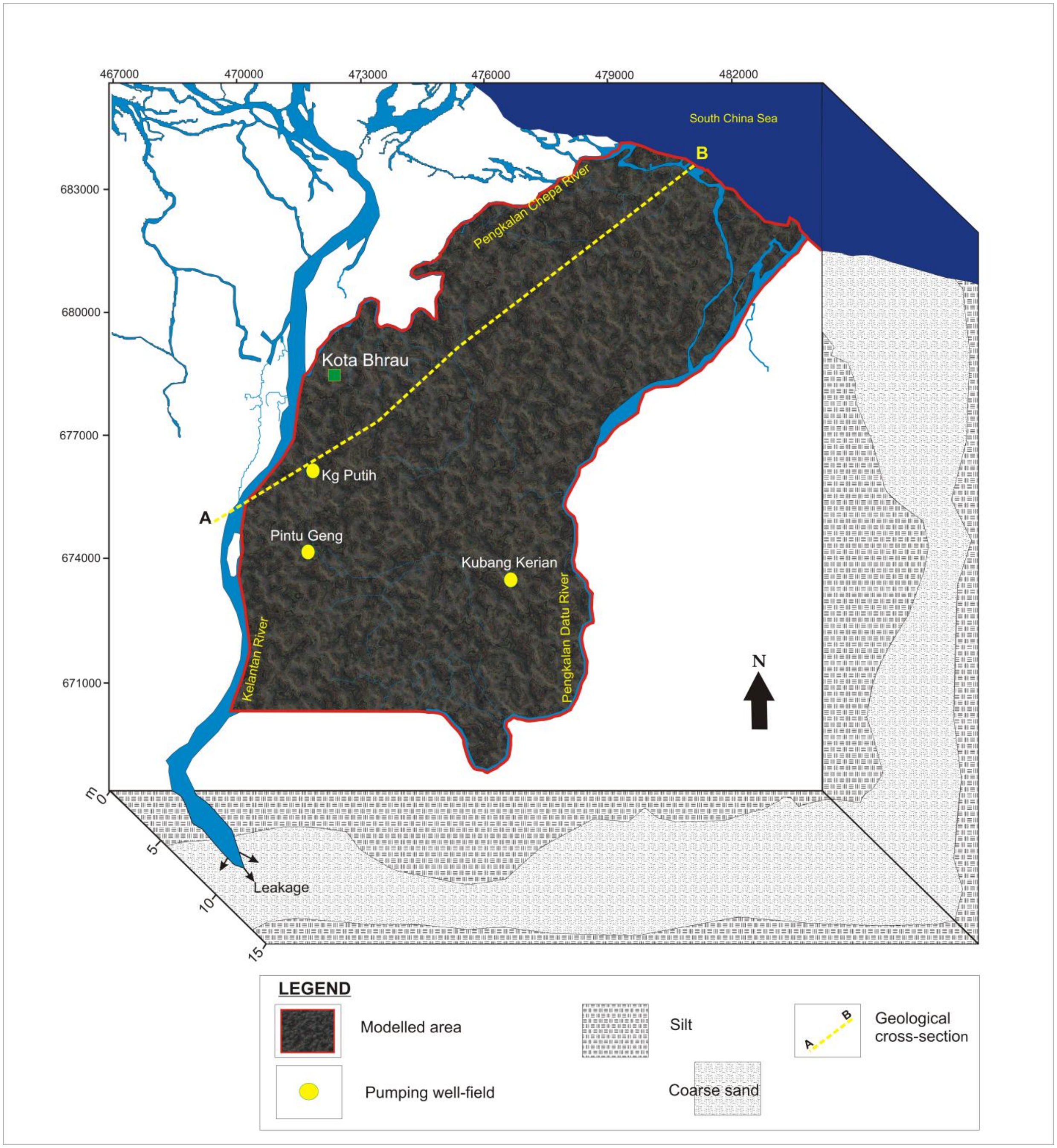

Figure 4.16 : Conceptual model of North Kelantan Aquifer

4.9.2.4 Numerical Modeling

Groundwater modeling is accomplished by using MODFLOW a modeling program developed by the USGS. This is the most widely used finite-difference groundwater model and considered a standard for groundwater modeling. The development of input files are compiled using Visual Modflow a commonly used pre-processor of data that is used to speed up and facilitate the development of the MODFLOW model. The proposed pilot groundwater model for North Kelantan is shown in Figure 4.17.

A 3-dimensional representation of the Site was created in Visual MODFLOW. This model domain was created as a 17200m by 17200m mesh in the X and Y (corresponding with east-west and north-south, respectively) directions, respectively, with a general uniform grid spacing of 345m between grid nodes (Figure 4.17). Vertically, the grids are refined to:

i. 0.2 m uniform spacing between nodes in the area around Pintu Geng well field.
ii. 23m uniform spacing between nodes around the active pumping well fields. However Pengkalan Chepa (inactive well field) also included for prediction purpose.
iii. 69m uniform spacing between nodes of the pumping well fields in the area where groundwater development takes place (Figure 4.17).

Horizontally, finer spacing is designed for the well field in Pintu Geng up to 8 inch (0.2m) x 1m grid size in order to handle the horizontal well designed diameter, as a result, the horizontal refining process was only limited to immediate area around the Pintu Geng because the maximum number of rows in Modflow discretization process shouldn't exceed 499 rows.

The discretization of the modelled area consists of 50 columns and 50 rows. The areas surrounding the modelled area are made inactive. A digitized map of the study area was superimposed on the model as a base map. The model consists of two layers. These include layer1 (~4 m of silty soil) and layer 2 (~10m of coarse sand) which represents the shallow aquifer in the Kelantan area. The less permeable layer on the surface that partially confined the aquifers has been modelled as a continuous layer with a reasonable value of hydraulic conductivity (1E-7 m/s).

4.9.2.5 Boundary Conditions

As shown in Figure 4.16, the South China Sea in the north-eastern boundary of the modelled area was assigned as constant head. River boundaries were assigned for the northern, eastern (and south-eastern), and western edges of the modelled area which bound by three rivers which namely include Pengkalan Chepa, Pengkalan Datu, and Kelantan. All the rivers have been modelled using the River Package of MODFLOW groundwater model.

A value of between 5% and 20% of annual precipitation is recommended as an estimate of recharge when other data are not available (Waterloo, 2005). Based on this guidance, recharge was set equal to 12% of average annual precipitation subject to revision through model calibration and validation.

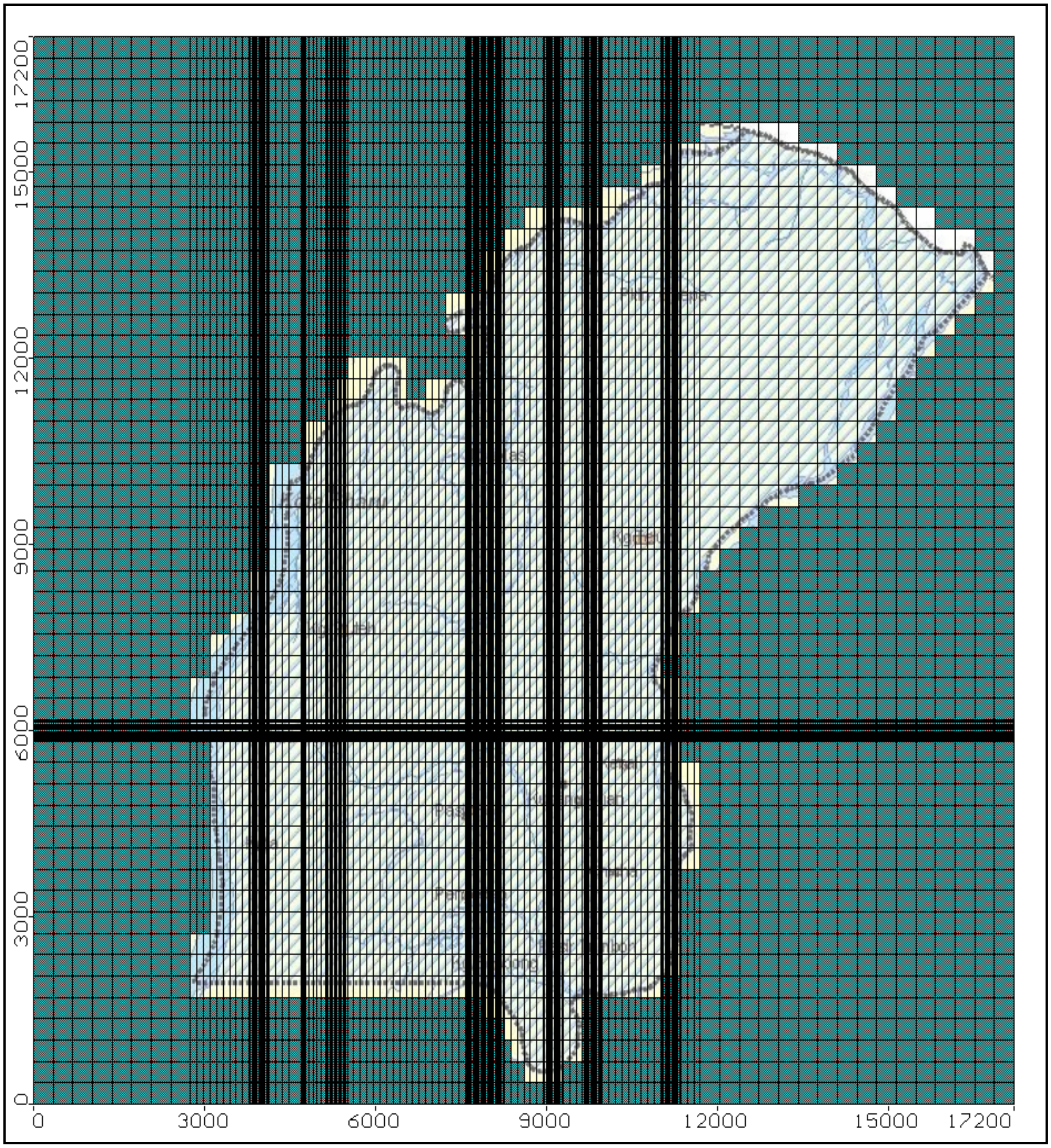

Figure 4.17: Proposed coverage of North Kelantan aquifer system with the model grid area for pilot aquifer model

4.9.2.6 Model Calibration and Validation

The Visual MODFLOW model was run at transient state then calibrated to hydraulic heads recorded in monthly rate from January 2000 to December 2005 at six groundwater monitoring wells for calibration. Table 4.10 presents parameters of the calibrated model. Most of the groundwater monitoring wells are located outside the well field and within the modelled area.

Model calibration consists basically of modifying the recharge and conductance parameters to minimize the error between predicted and observed heads. Estimated recharge rate is to be 12% of the rainfall. The model validated to hydraulic heads recorded in monthly rate from January 2009 to December 2010 at six groundwater monitoring wells located on-site. Estimated recharge rate is 12% of the average rainfall.

Table 4.10 : Parameters to be used for the Calibrated Model

<table>
<tr><th rowspan="2">Parameter</th><th colspan="8">Value</th></tr>
<tr><td colspan="2">Zone 1 (Silt)</td><td colspan="3">Zone 2 (coarse sand)</td><td colspan="3">Zone3 (Fine sand)</td></tr>
<tr><td>Kx (m/s)</td><td colspan="2">1E-7</td><td colspan="3">0.006</td><td colspan="3">0.0002</td></tr>
<tr><td>Ky(m/s)</td><td colspan="2">1E-7</td><td colspan="3">0.006</td><td colspan="3">0.0002</td></tr>
<tr><td>Kz(m/s)</td><td colspan="2">1E-8</td><td colspan="3">0.0006</td><td colspan="3">1E-5</td></tr>
<tr><td colspan="9"></td></tr>
<tr><td>Ss</td><td colspan="8">1E-5</td></tr>
<tr><td>Sy</td><td colspan="8">0.27</td></tr>
<tr><td>Recharge</td><td colspan="8">12% of rainfall</td></tr>
<tr><td>Total Porosity</td><td colspan="8">0.20</td></tr>
<tr><td>Effective porosity</td><td colspan="8">0.11</td></tr>
<tr><td colspan="9"></td></tr>
<tr><td></td><td colspan="2">Kelantan River</td><td colspan="3">Pengkalan Datu</td><td colspan="3">Pengkalan Chepa</td></tr>
<tr><td>Conductance (m^2/day)</td><td colspan="2">309</td><td colspan="3">305</td><td colspan="3">278</td></tr>
<tr><td colspan="9"></td></tr>
<tr><td rowspan="2">Groundwater pumping (m^3/day)</td><td>Kubang Kerian</td><td>Pasir Hor</td><td>Pintu Geng</td><td>Pasir Tumboh</td><td>Kg Sbg</td><td>Kota</td><td>Kg Puteh</td><td>Pdp</td></tr>
<tr><td>10800</td><td>14680</td><td>8000</td><td>4200</td><td>7800</td><td>10000</td><td>27200</td><td>8800</td></tr>
</table>

Kg: Kampung (village); Sbg: Seribong; Pdp: Penyadap

4.9.2.7 Calibration Results

Model calibration is aimed at minimizing the normalized residual mean squared (*nRMS*) error and maximizing the correlation coefficient (*r*) between predicted and observed groundwater heads by modifying the conductance parameters and recharge parameters. Usually in the early stages of any simulation, any model experiences some instability due to un-equilibrium condition. Thus, the earlier stages of the current model simulation are considered the stages of un-equilibrium between aqueous and dry phases.

Following calibration, of the MODFLOW groundwater flow model exhibits *nRMS* and *r* ranges between 19 – 67 % and 0.70 – 0.90 respectively as presented in the calibration plots for the calculated and observed heads (Figures 4.18 to 4.25). Figure 4.26 illustrates the simulated and observed head versus time. The storage is 80,655,448 m^3/day and the model was calibrated up to 95% confidence interval.

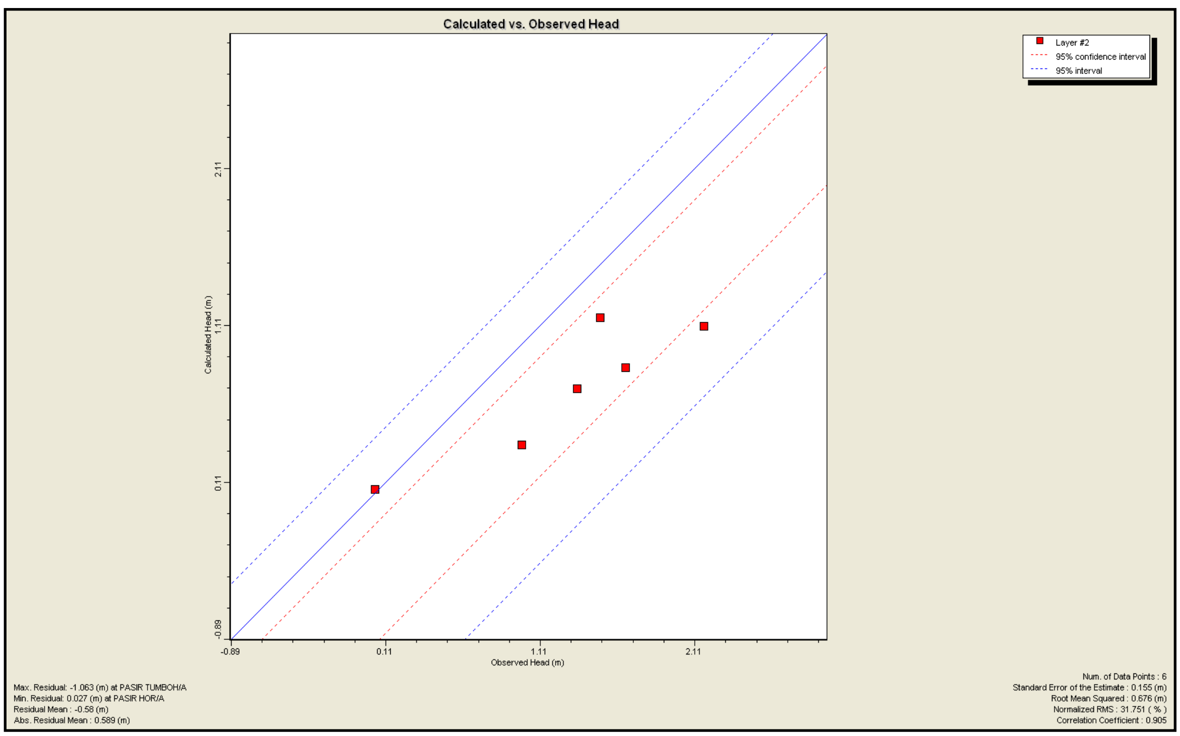

Figure 4.18: Calibration scatter plot – stress period 35

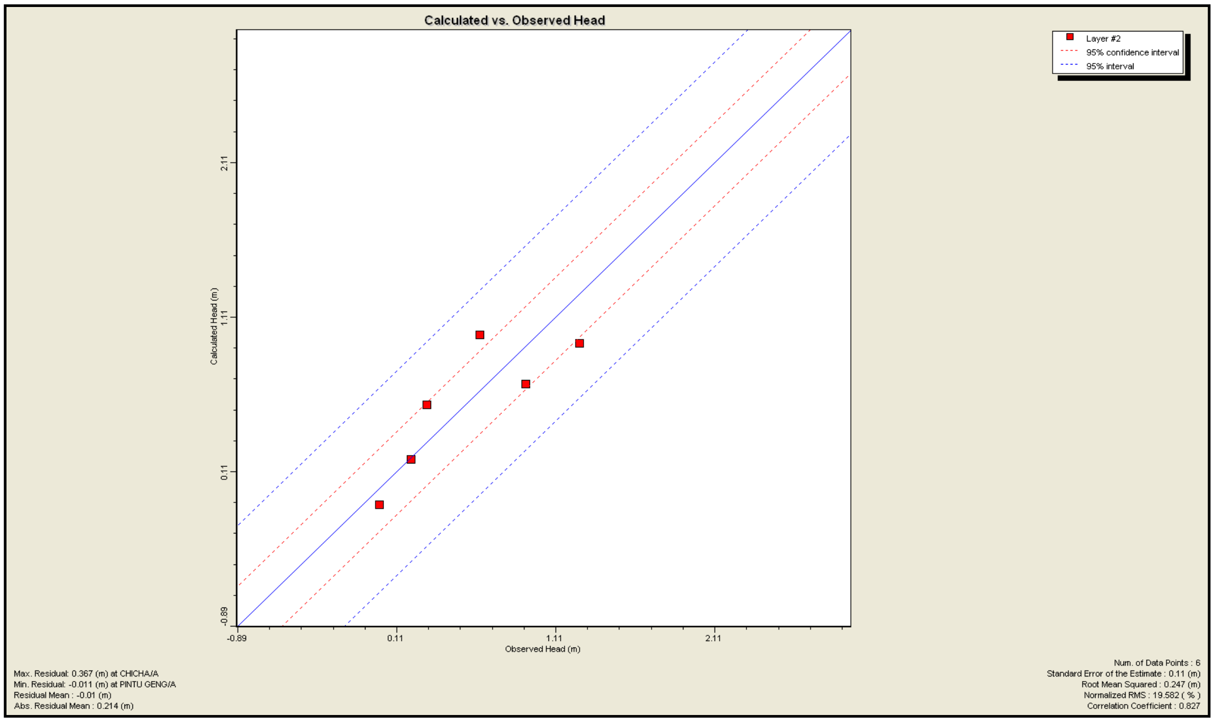

Fig.4.19: Calibration scatter plot – stress period 38

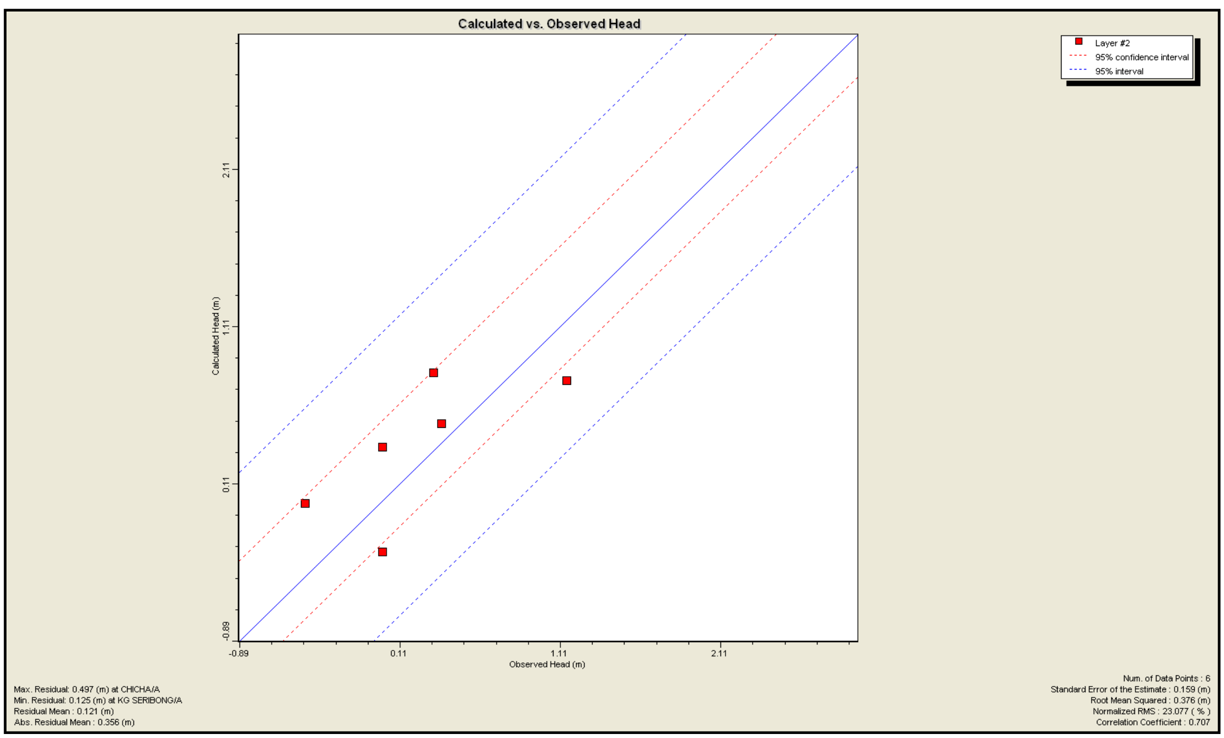

Figure 4.20: Calibration scatter plot – stress period 41

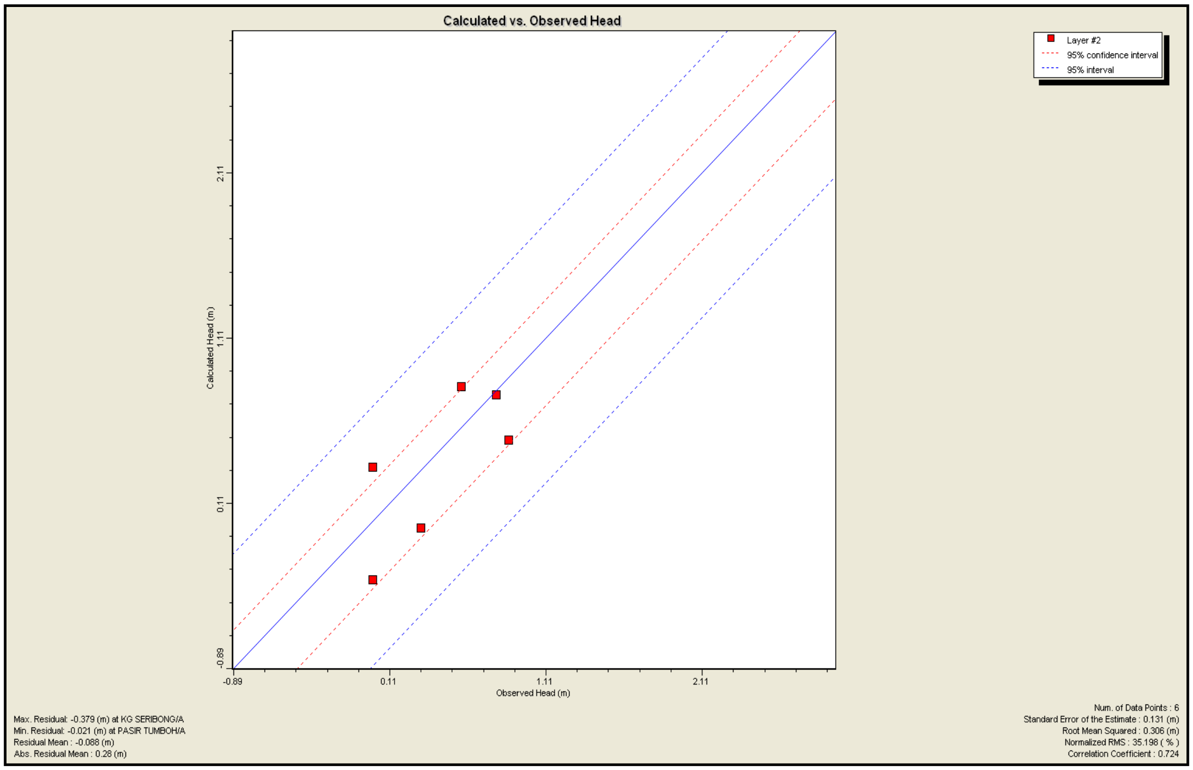

Fig. 4.21: Calibration scatter plot – stress period 44

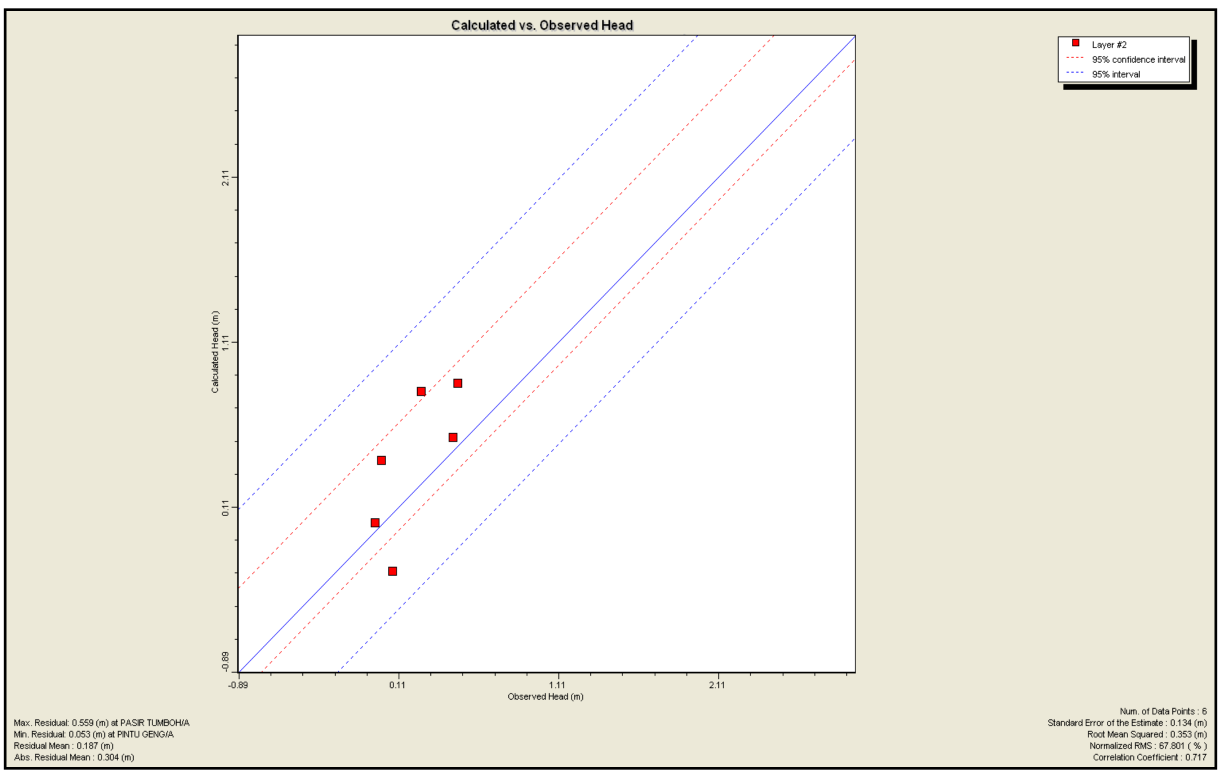

Fig. 4.22: Calibration scatter plot – stress period 50

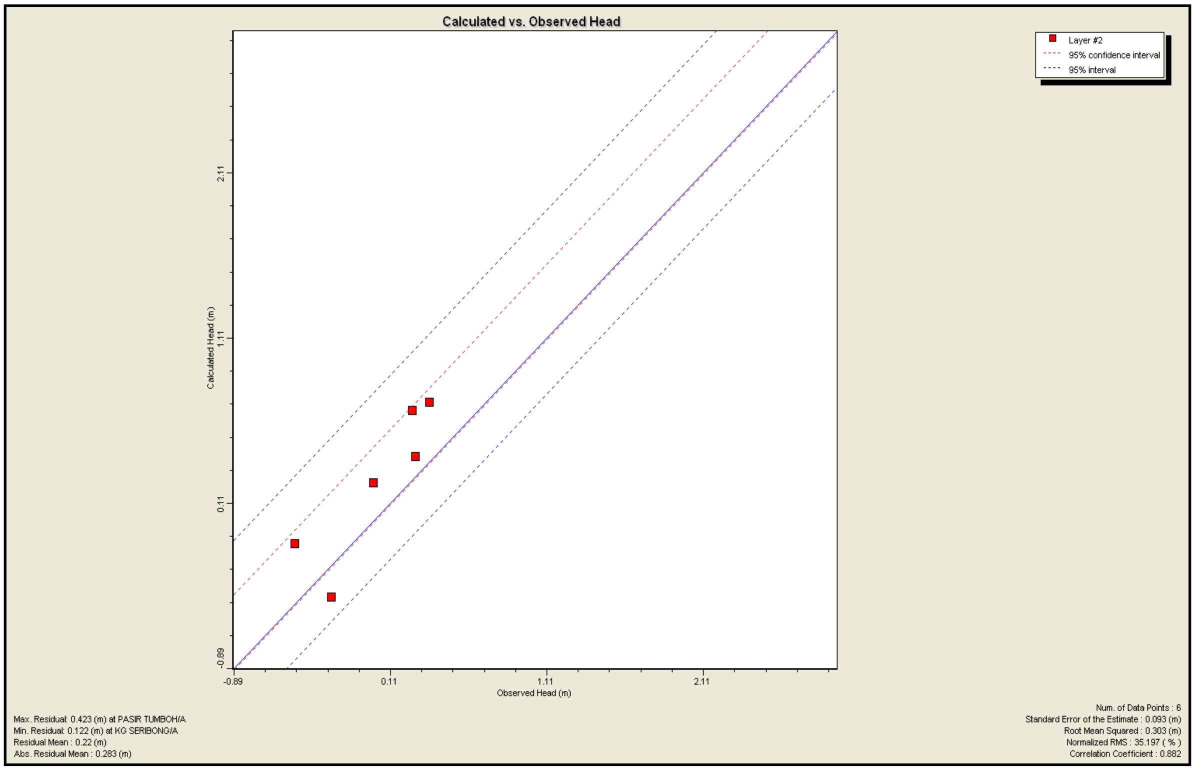

Fig.4.23: Calibration scatter plot – stress period 53

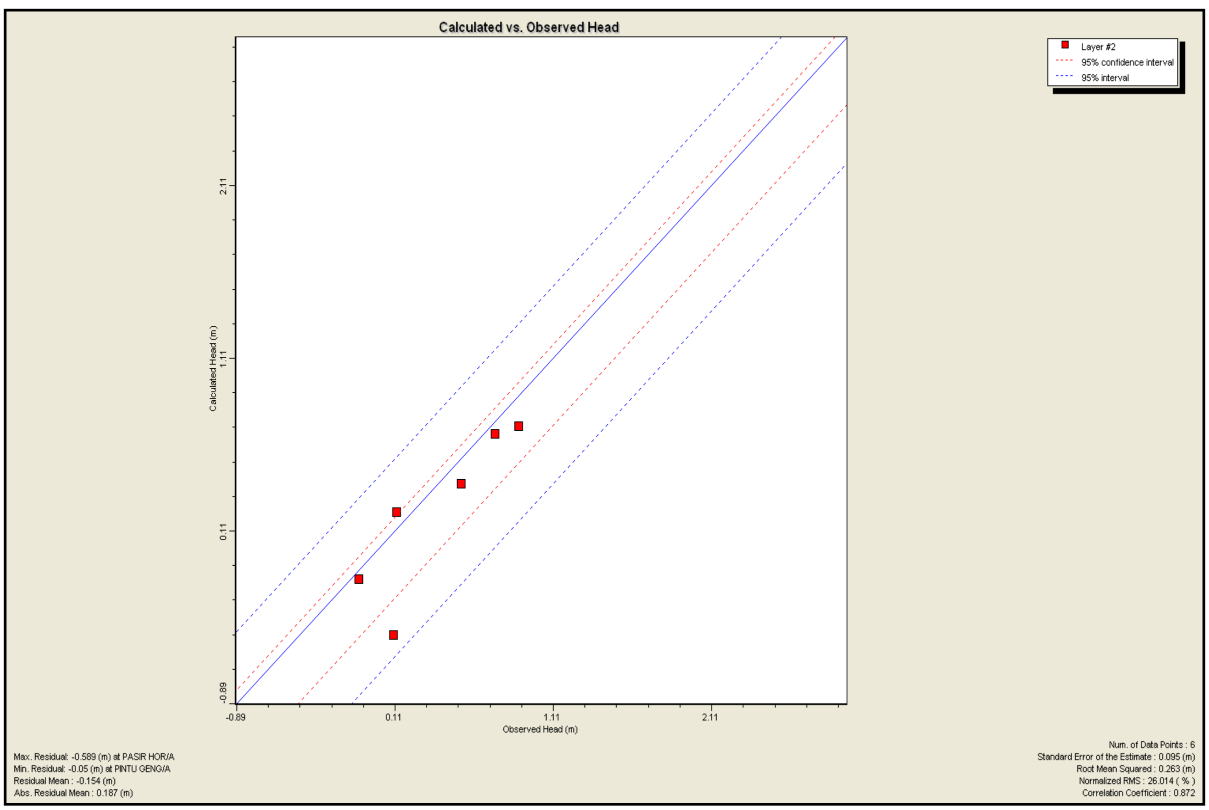

Fig.4.24: Calibration scatter plot – stress period 57

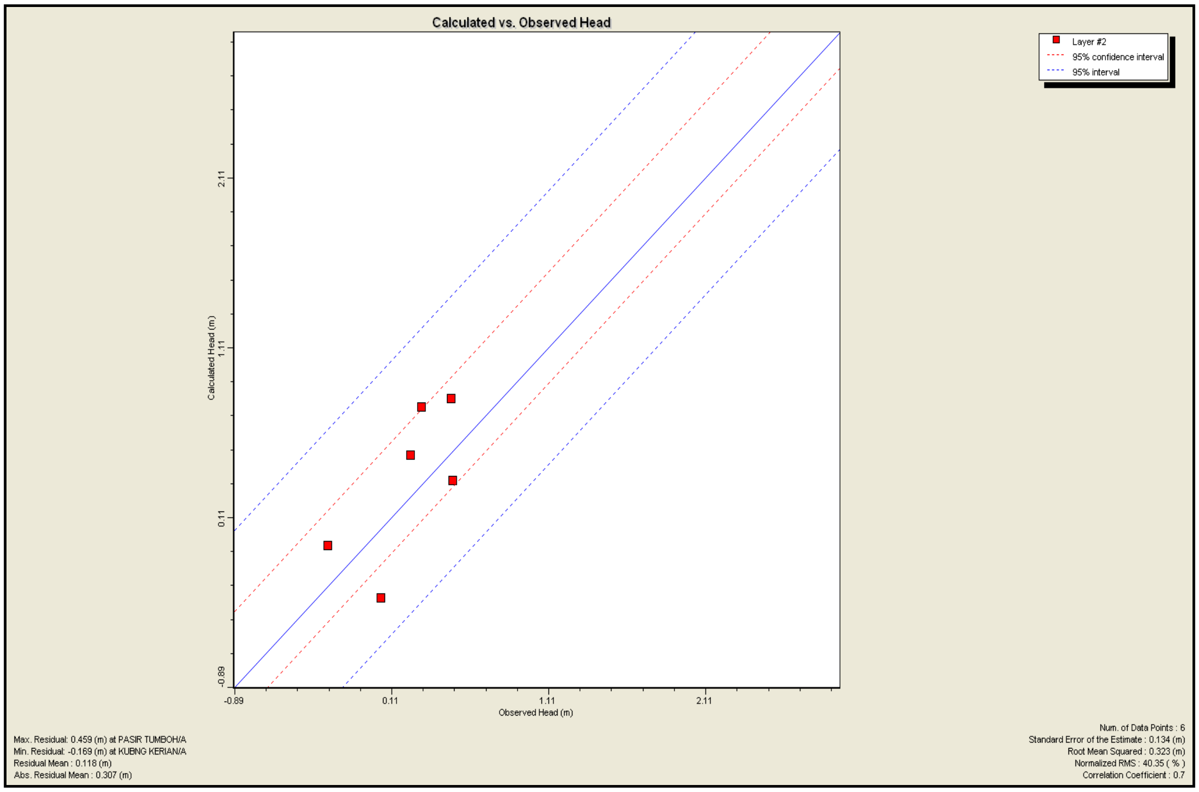

Fig.4.25: Calibration scatter plot – stress period 62

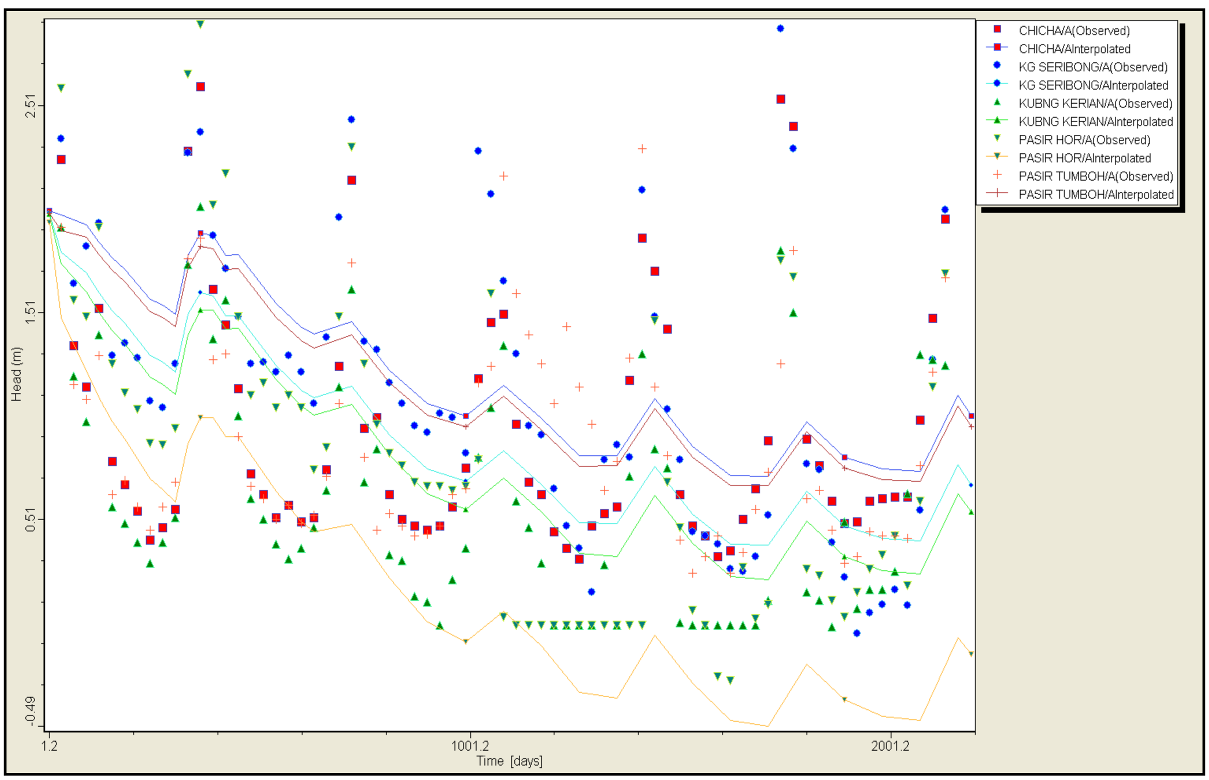

Fig. 4.26: Head versus time during the calibration period

4.9.2.8 Validation

For validation process, a transient simulation of groundwater heads was performed and then the calculated values were compared to most recent set of transient data of groundwater heads and rainfall (estimated recharge) recorded during the period January 2009 – December 2010.

Following calibration, of the MODFLOW groundwater flow model exhibits *nRMS* and *r* ranges between 20 – 46% and 0.75 – 0.86 respectively as presented in the calibration plots for the calculated and observed heads (Figures 4.27 to 4.34). Figure 4.35 illustrates the simulated and observed head versus time. The model was calibrated up to 95% confidence interval.

The results of the model validation indicate that predicted head values correlate well with heads observed compared to calibration period.

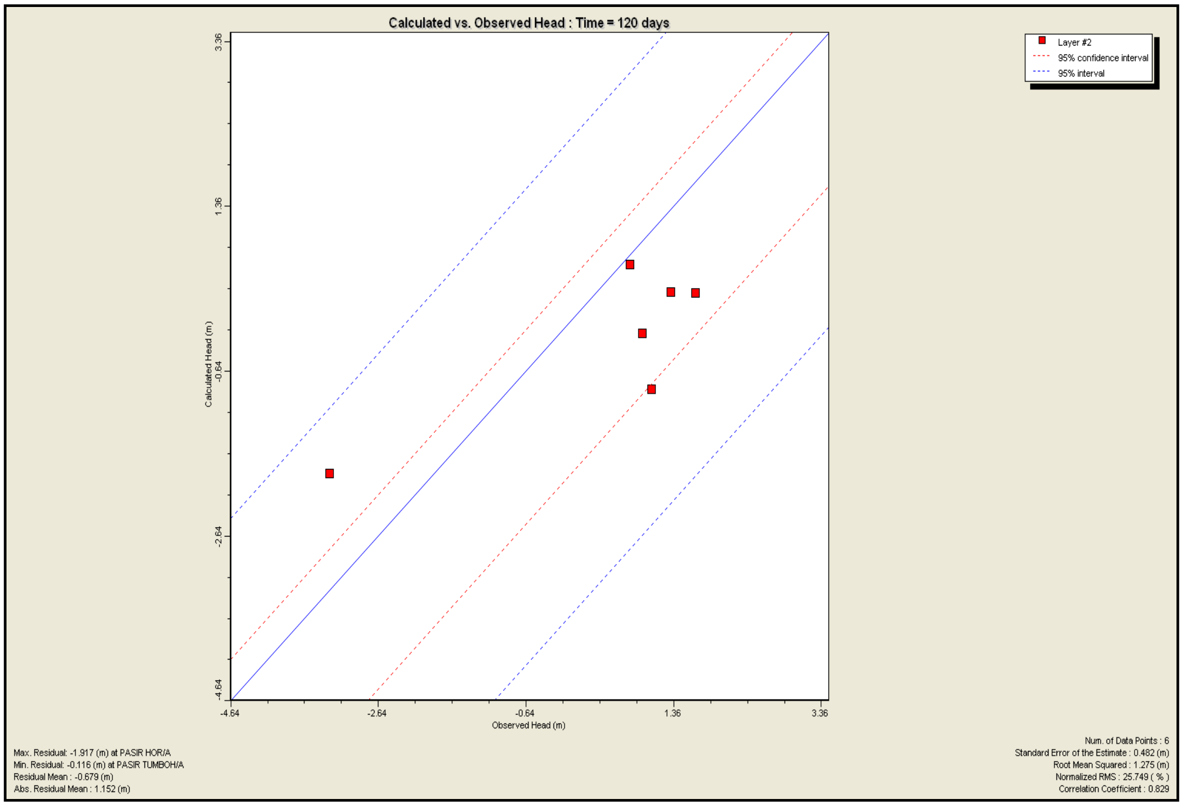

Fig.4.27: Calibration scatter plot – stress period

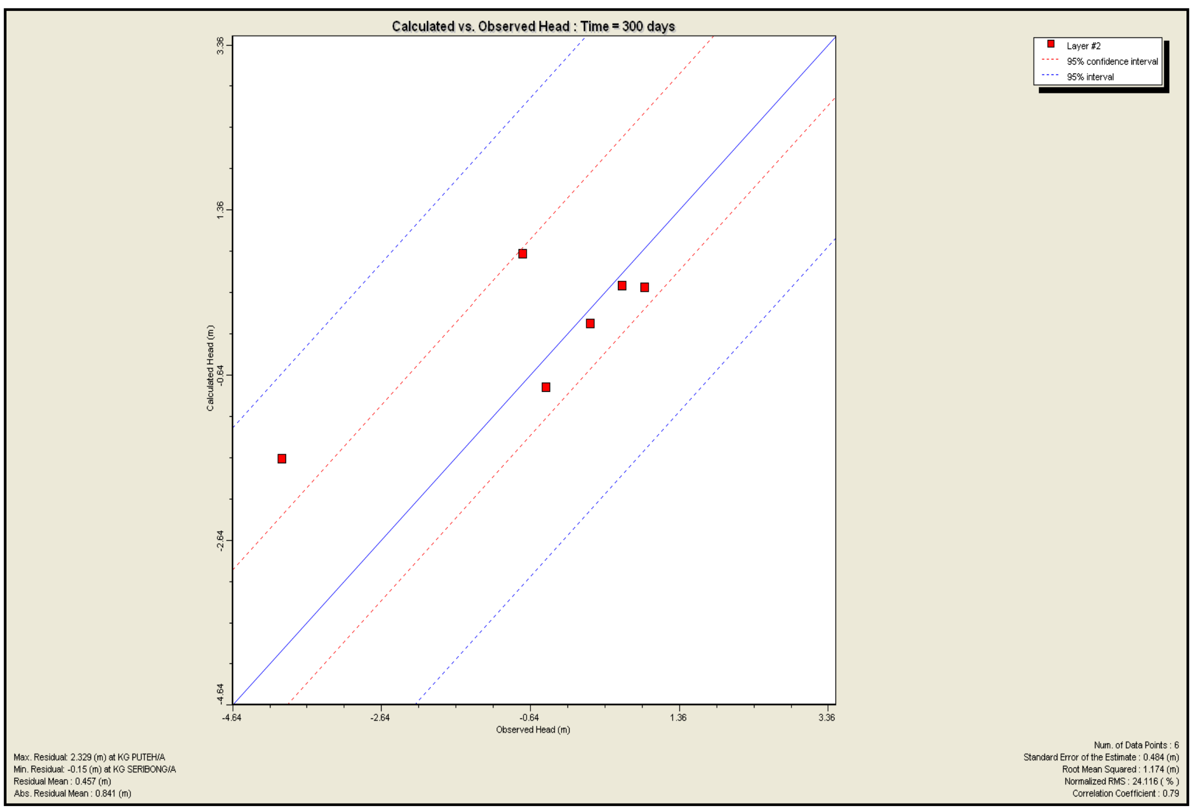

Fig.4.28: Calibration scatter plot – stress period

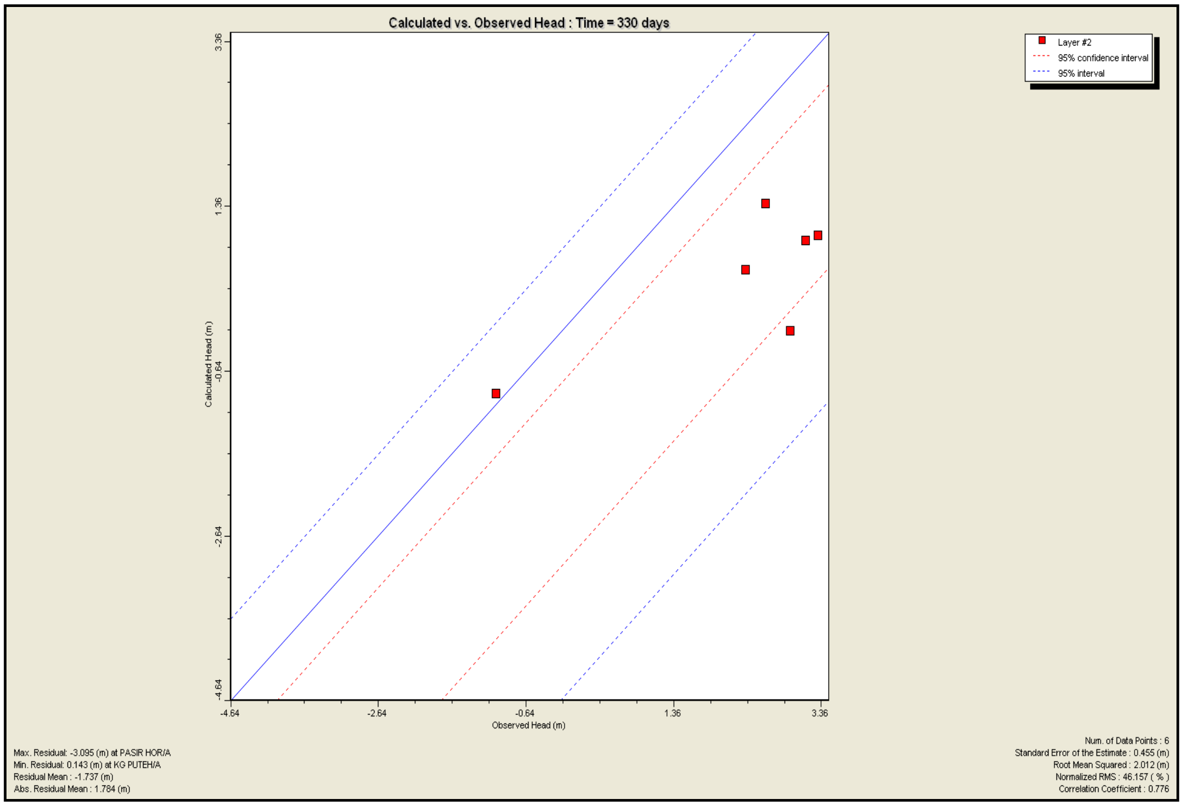

Fig.4.29: Calibration scatter plot – stress period

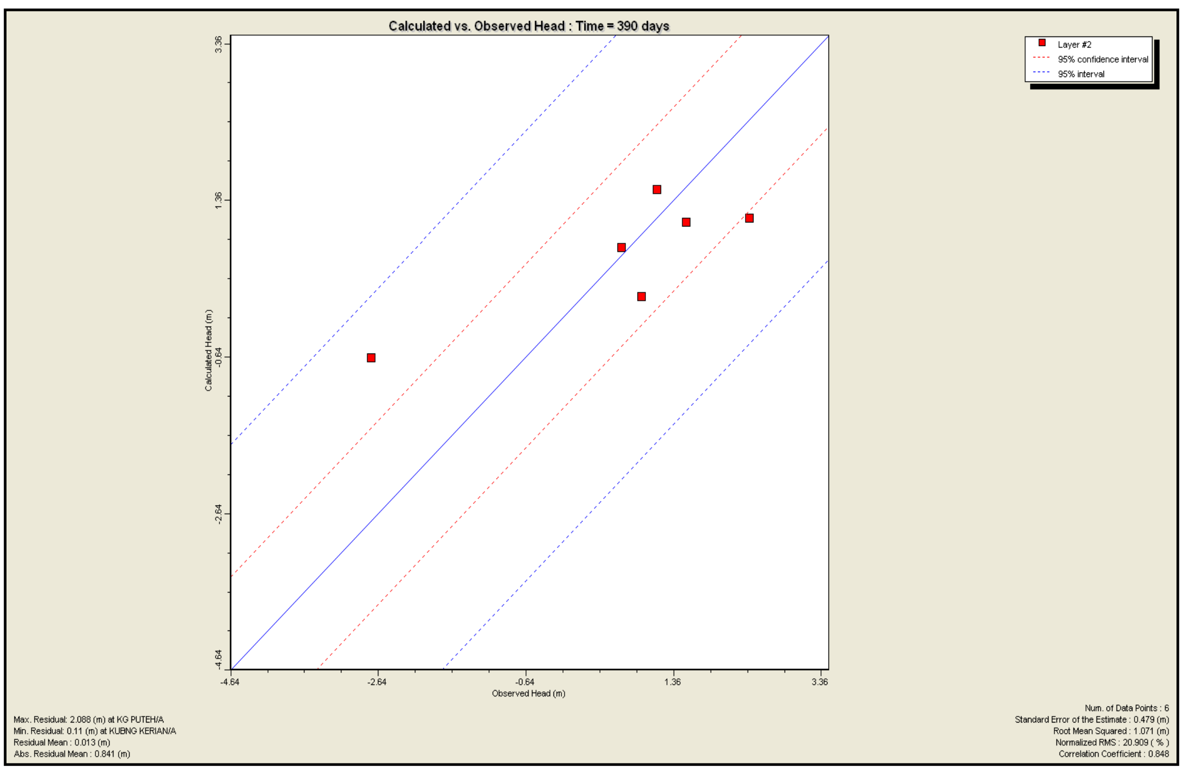

Fig.4.30: Calibration scatter plot – stress period 13

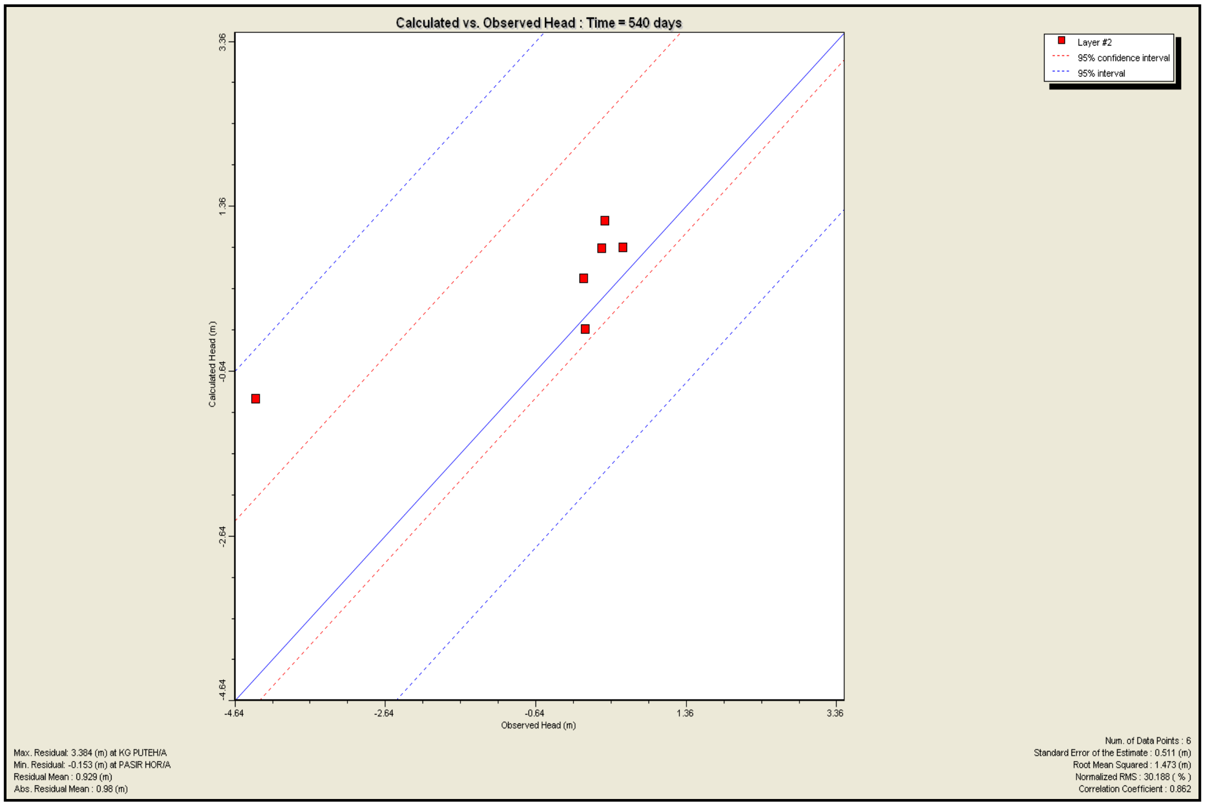

Fig.4.31: Calibration scatter plot – stress period 16

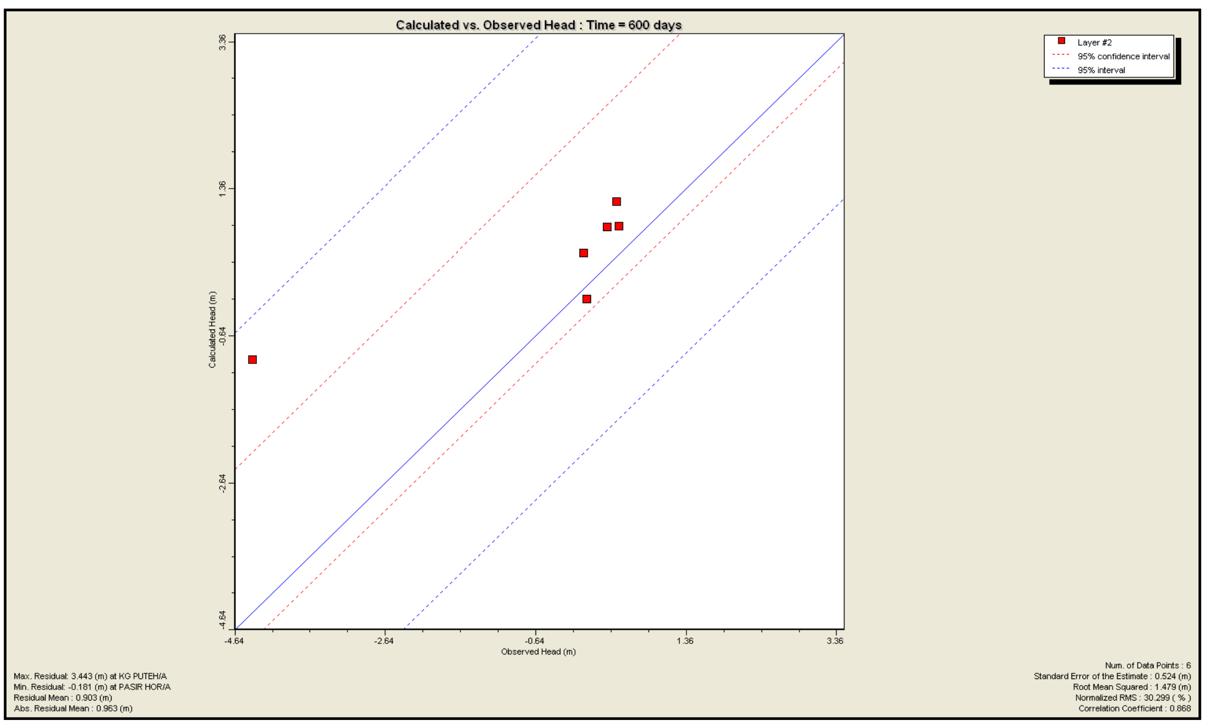

Fig.4.32: Calibration scatter plot – stress period 17

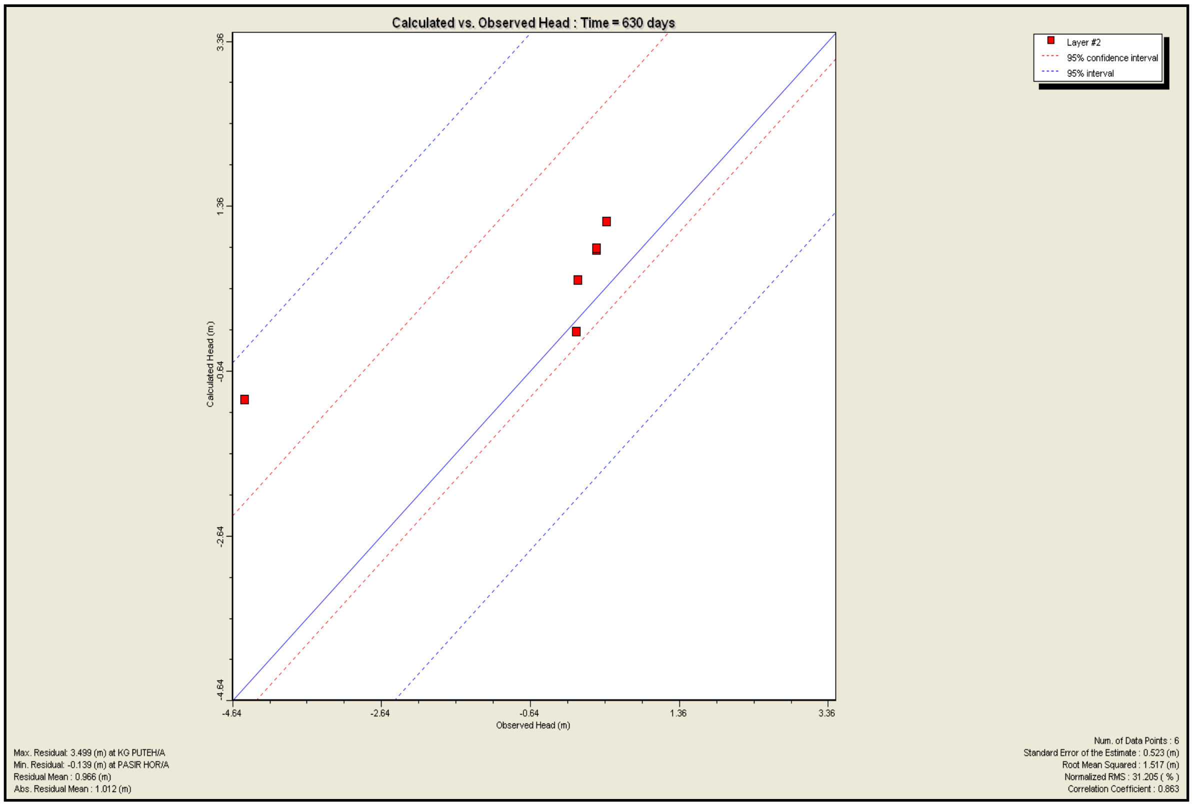

Fig.4.33: Calibration scatter plot – stress period 18

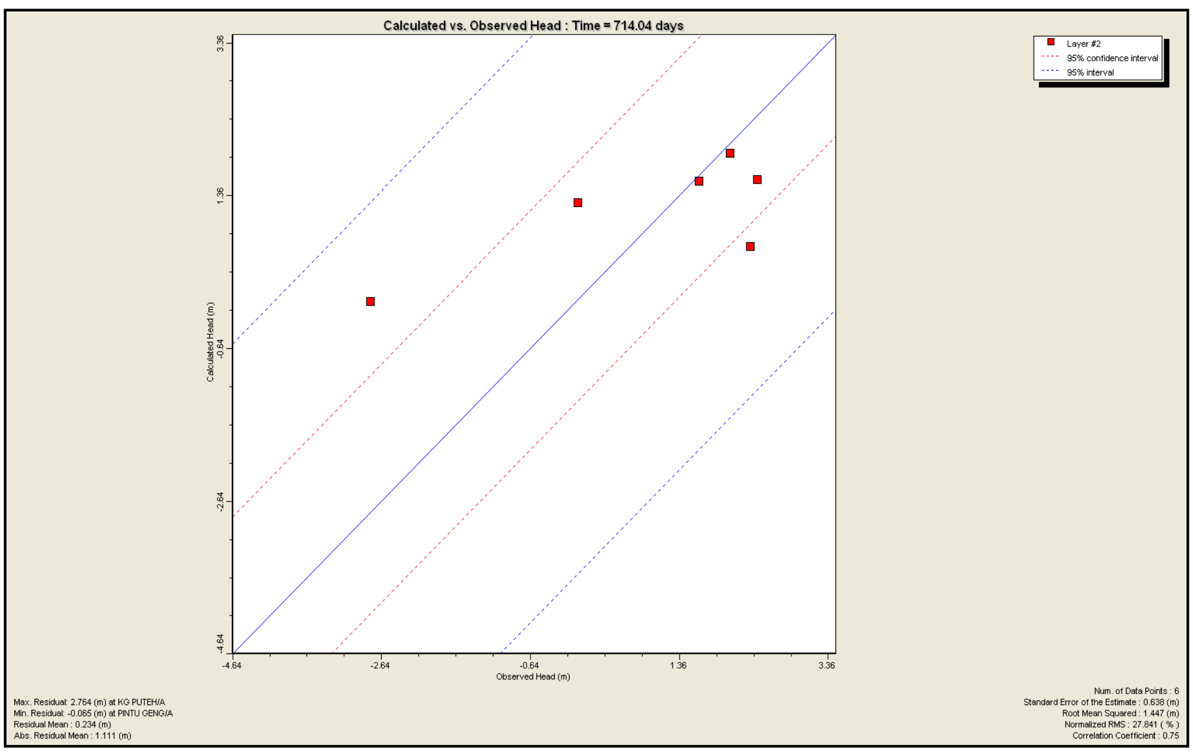

Fig.4.34: Calibration scatter plot – stress period 19

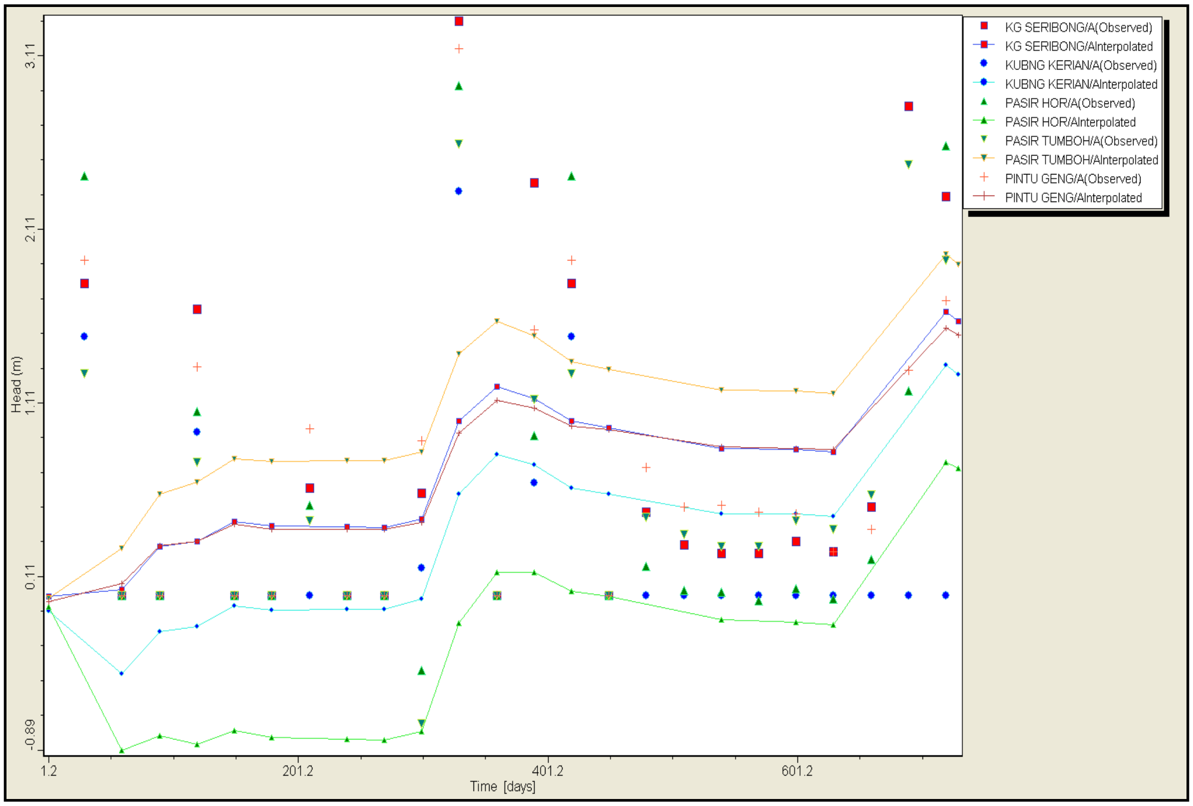

Fig.4.35: Head versus time during the validation period

4.10 MODEL RESULTS

4.10.1 Updating Hydrogeological Information: Groundwater head and flow pattern

In general groundwater in the aquifer layer flows towards the South China Sea and nearby rivers under normal conditions. However, at present time, groundwater is flowing towards the well fields to support the abstraction rate (Figure 4.36).

Some of the groundwater flows towards the sea especially in the lower part of the basin. Rivers also support the abstraction rate by the well fields (Fig. 4.36). Groundwater head ranges between 0.0 – -6.0 m (m.s.l) upstream part of the modelled area where groundwater development steadily and extensively takes place.

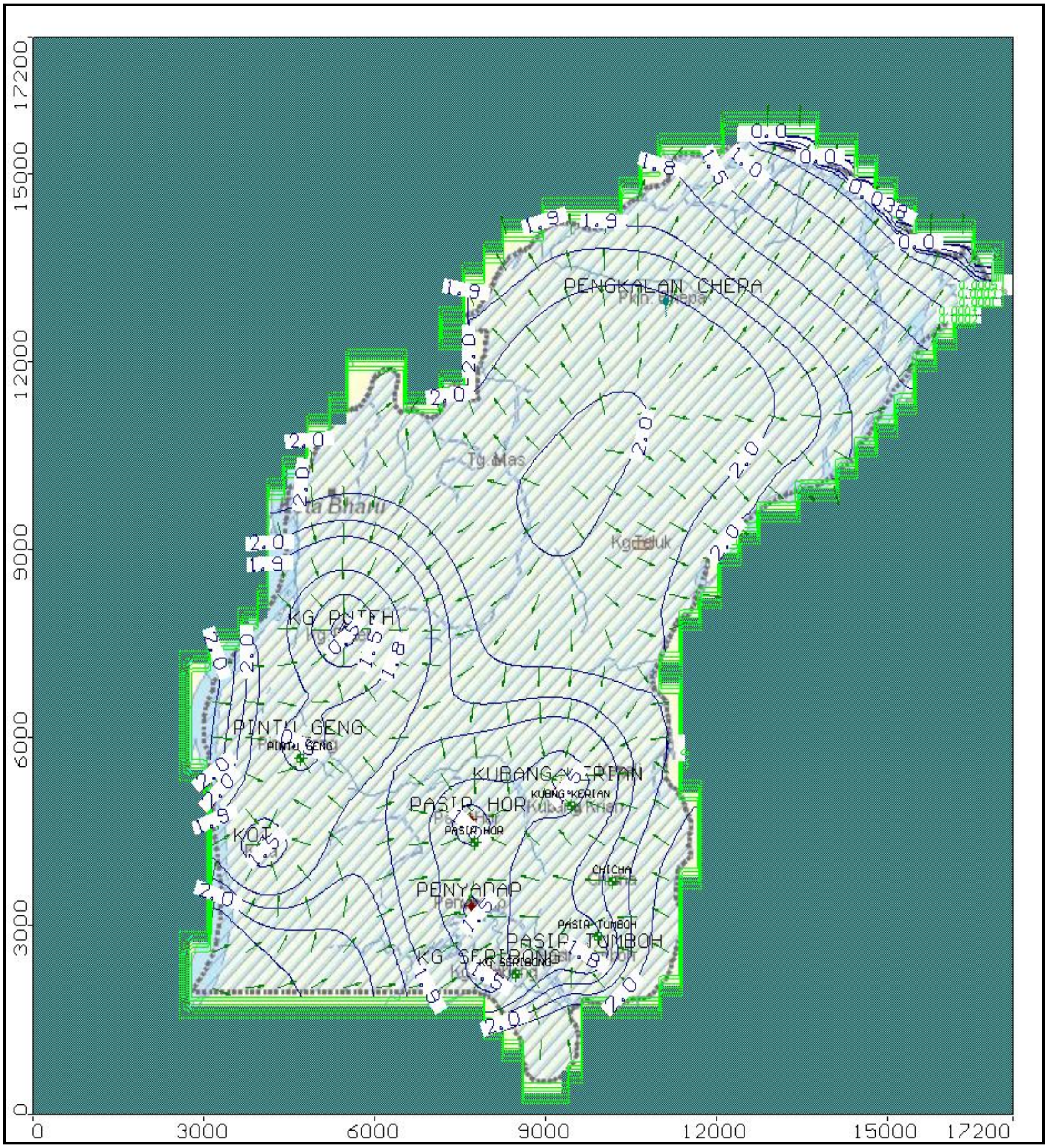

Fig. 4.36: Groundwater head and flow pattern

4.10.2 Delineation of capture zones

The present pumping rate creates two dominant groundwater capture zones (Fig.4.37). These include:

a) Upstream capture zone: this developed due to the present pumping condition at present rate.

b) Downstream capture zone: this developed due to natural flow gradient and groundwater discharge towards the South China Sea.

However, some eight sub-capture zones of different diameters have been developed around the existing well-fields within the upstream capture zone (Figure 4.37). These include: Pasir Hor, Penyadap, Kg Puteh, Pintu Geng, Kota, Kubang Kerian, Kg Seribong and Pasir Tumboh (Table 4.11).

Table 4.11: Capture Zones around each Well-Field

Well Field	Capture Zone (km)
Pasir Hor	North: ≈2.5; North-west: ≈1.5; South: ≈0.7; South-east: ≈4.0; East≈0.5; West: ≈2.0
Penyadap	North: ≈.0.5; South: ≈0.6; West: ≈1.7 East≈1.5; South-west ≈2.2; West-south-west: ≈3.0
Kg Puteh	North: ≈4.5; South: ≈1.5; East≈3.0; West: ≈1.5;North-east: ≈4.5
Pintu Geng	North: ≈1.0; South: ≈0.5; East≈1.5;West: ≈2.0
Kota	North: ≈0.7; South: ≈2.0; East≈1.5;West: ≈0.8
Kubang Kerian	North≈0.6; North-east: ≈2.2; South: ≈0.3; East≈1.4; West: ≈0.3; South-east: ≈2.5
Seribong	North≈0.5; North-east: ≈1.2; South: ≈0.4; East≈1.0; West: ≈0.4; South-east: ≈2.0
Pasir Tumboh	North≈0.8; North-east: ≈1.8; South: ≈0.9; East≈1.7; West: ≈0.4; South-east: ≈1.0; South-east: ≈2.2

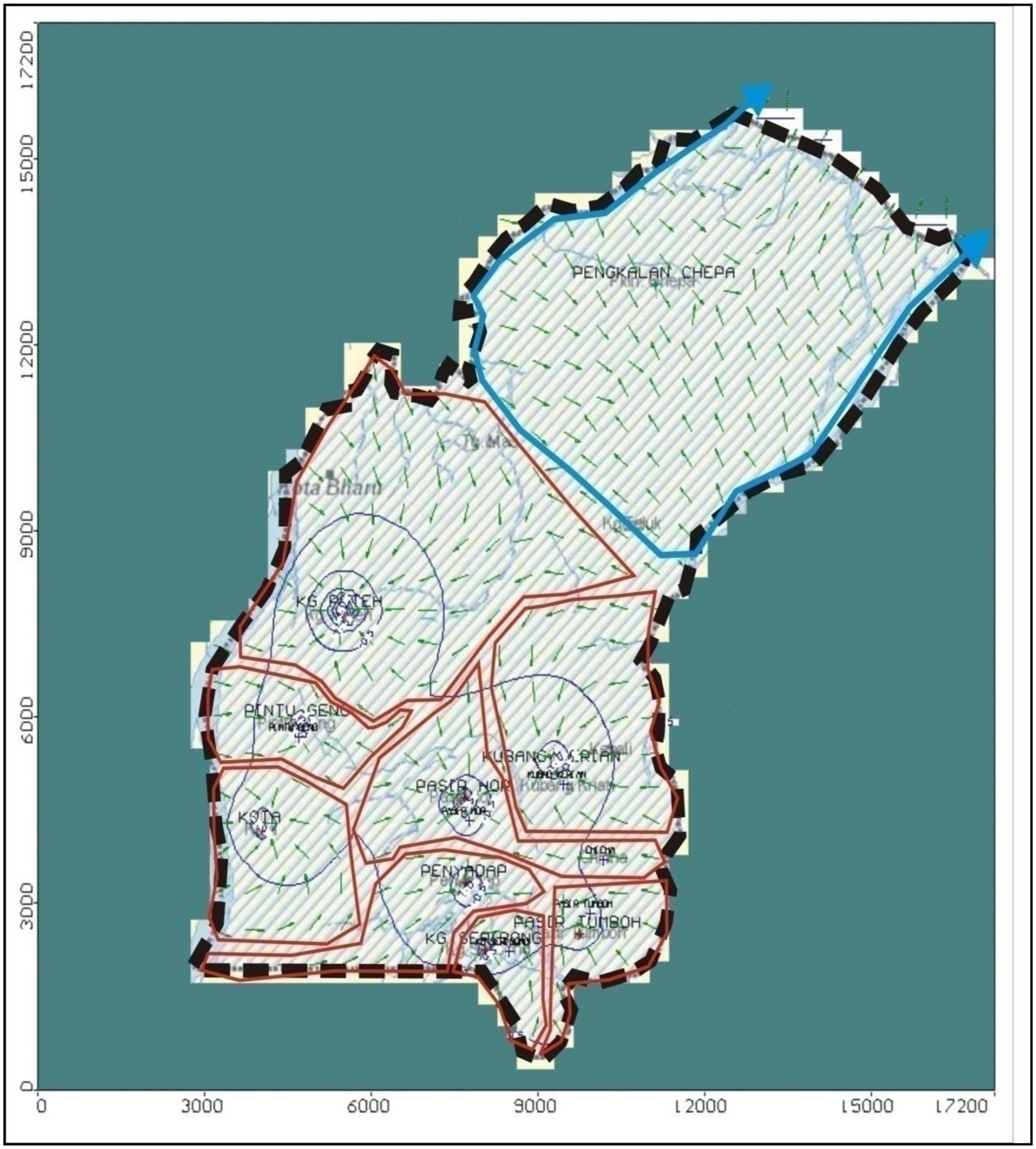

Fig. 4.37: Capture zones of the present field

4.10.3 Water Balance

The results of cumulative volume water balance and exchange fluxes are based on the calibration and validation simulations of the entire modelled catchment

(Zone 1) as well as for the at the last time step of simulation at the sub-catchment of Pintu Geng capture zone (Zone 2) (Figure 4.38; Tables 4.12 and 4.13).

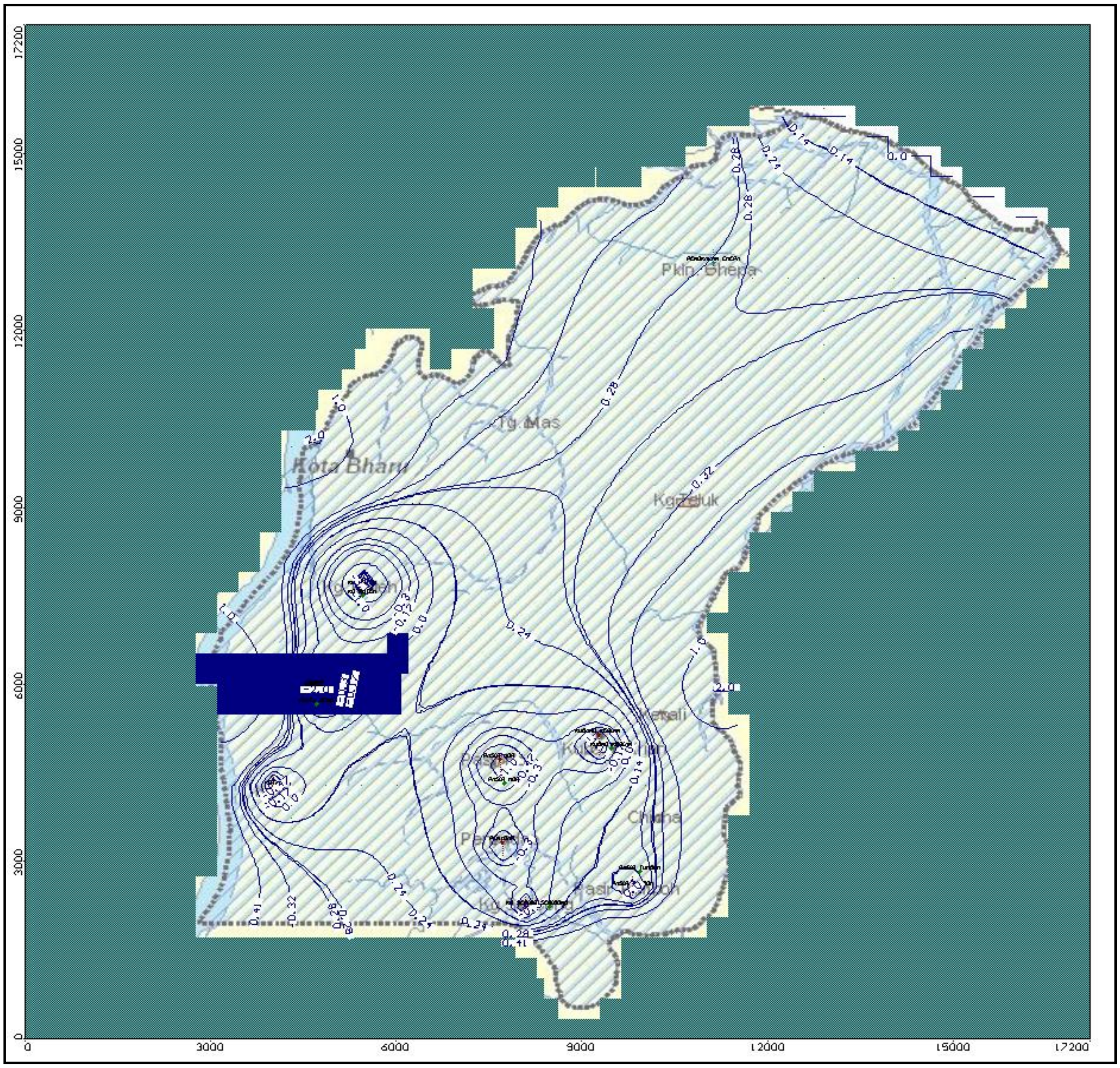

Fig. 4.38: Water budget zones. Zone 1 (white) represents the modelled area. Zone 2 (Blue) represents Pintu Geng capture Zone

Table 4.12 : Water Balance for the Modelled area

Simulation	Parameter	Inflow (m^3/day)	Outflow (m^3/day)
Calibration Jan 2000 – Dec 2005 (2192 days)	Storage	80,655,448	50867388
	Constant Head	0	47920592
	Wells	0	200524496
	Drains	0	0
	MNW	0	0
	Recharge	169732848	0
	ET	0	0
	River Leakage	63400584	14667527
	Stream Leakage	0	0
	General-Head	0	0
	Total	313788864	313980000
	Inflow - Outflow	-191136 (m^3/day)	
	Discrepancy	-0.06 %	
Validation Jan 2009 – Dec 2010 (730 days)	Storage	9965913	64455904
	Constant Head	0	10618
	Wells	0	71497664
	Drains	0	0
	MNW	0	0
	Recharge	102409280	0
	ET	0	0
	River Leakage	33402534	9716712
	Stream Leakage	0	0
	General-Head	0	0
	Total	145777728	145670272
	Inflow - Outflow	107456 (m^3/day)	
	Discrepancy	0.07%	

Table 4.13: Water Budget for Zone 2 (Pintu Geng Capture Zone)

Simulation	Parameter	Inflow (m^3/day)	Outflow (m^3/day)
Calibration Jan 2000 – Dec 2005 (2192 days)	Storage	2619.3	0
	Constant Head	0	0
	Wells	0	8000
	Drains	0	0
	MNW	0	0
	Recharge	0	0
	ET	0	0
	River Leakage	2349.6	14667527
	Stream Leakage	0	0
	General-Head	0	0
	Zone 1 to 2	5370.9	-
	Zone 2 to 1	-	2464
	Inflow - Outflow	10340 - 10464 = -124.1 (m^3/day)	
	Discrepancy	-1.19%	
Validation Jan 2009 – Dec 2010 (730 days)	Storage	3351.7	0.44259
	Constant Head	0	10618
	Wells	0	71497664
	Drains	0	0
	MNW	0	0
	Recharge	0	0
	ET	0	0
	River Leakage	6465	9716712
	Stream Leakage	0	0
	General-Head	0	0
	Zone 1 to 2	3940.6	-
	Zone 2 to 1	-	5656.9
	Inflow - Outflow	13757 – 13657 = 99.997 (m^3/day)	
	Discrepancy	0.73%	

4.10.4 Scenarios

i. *Impacts of Pintu Geng Horizontal Collector Well (PGHCW)*

Different scenarios were run to investigate the impact of pumping of PGHCW on the groundwater head and drawdown inside the PGHCW itself and also within a radius of some 300 m from the Pintu Geng well-field.

The horizontal wells were modeled using the Drain package of Modflow model. The horizontal well (drain) is 0.2m diameter and 50m long. The horizontal wells flow to the central collector well having diameter of 3m. The model setup for the horizontal and collector wells is shown in Fig. 4.39. The centre of the horizontal well (drain) was assigned as the drain elevation. The hydraulic conductivity within the drain was assigned thousand times higher compared to the aquifer value. The drain bed material was assumed to be the same as the aquifer material.

The results are presented in Table 4.14. The model demonstrates that under natural flow condition at -3 m depth, the six collectors (drains) may tap a volume of groundwater ranges between 19,200 – 43,700 m^3/day (12% of stress periods are above 30.000 m^3/day). The variation in the rate is due to the variation in the recharge input (12% of the monthly rainfall. This rate is feasible if considering that the model is running the pumping for 24 hour a day, while in reality pumping process is much less lasting than in the model. On the other hand, it seems that as much as deepening the location of the collectors (drains) is considered i.e. up to -6 m, the more water can be tapped (Table 4.14). This situation is basically due to the remarkable increase of hydraulic gradient which in turn, increases the rate of groundwater flow into the drains regardless the seasonal fluctuations of the watertable. In both cases the predicted drawdown of 0.5 – 1.0 m (Figures 4.40 and 4.41) is within the safe limit (maximum limit is 3 m for this area around the PGHCW).

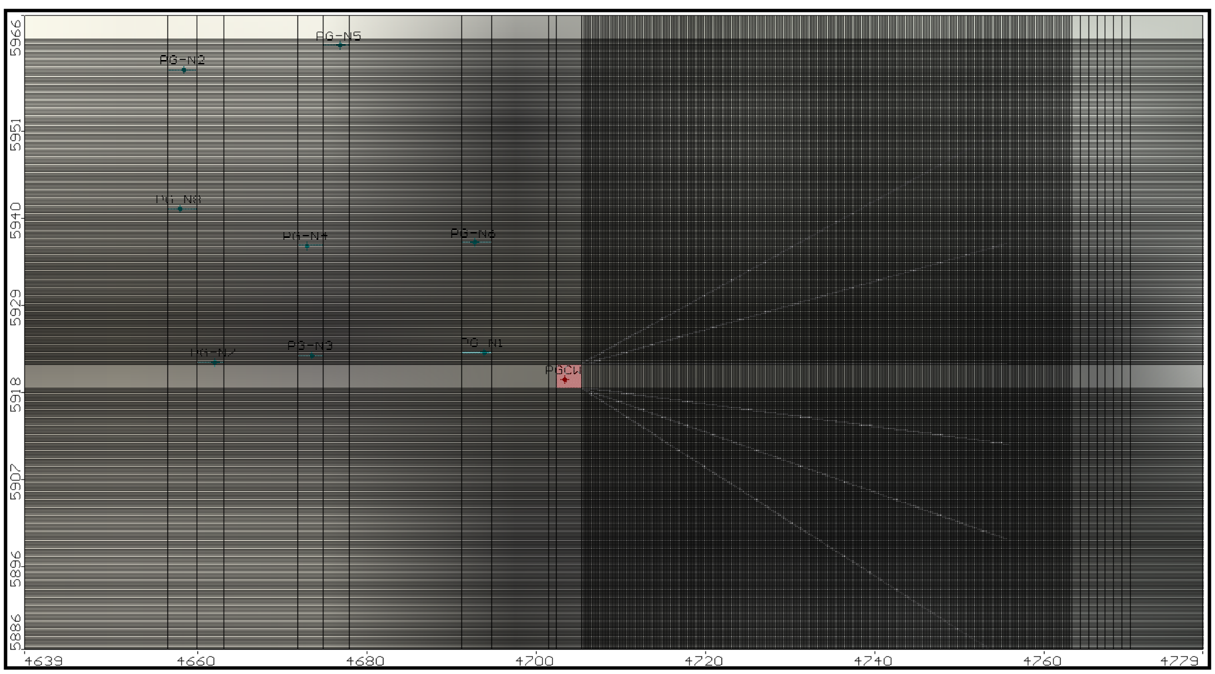

Fig. 4.39: Layout of Pintu Geng well-field and the horizontal well PGHCW

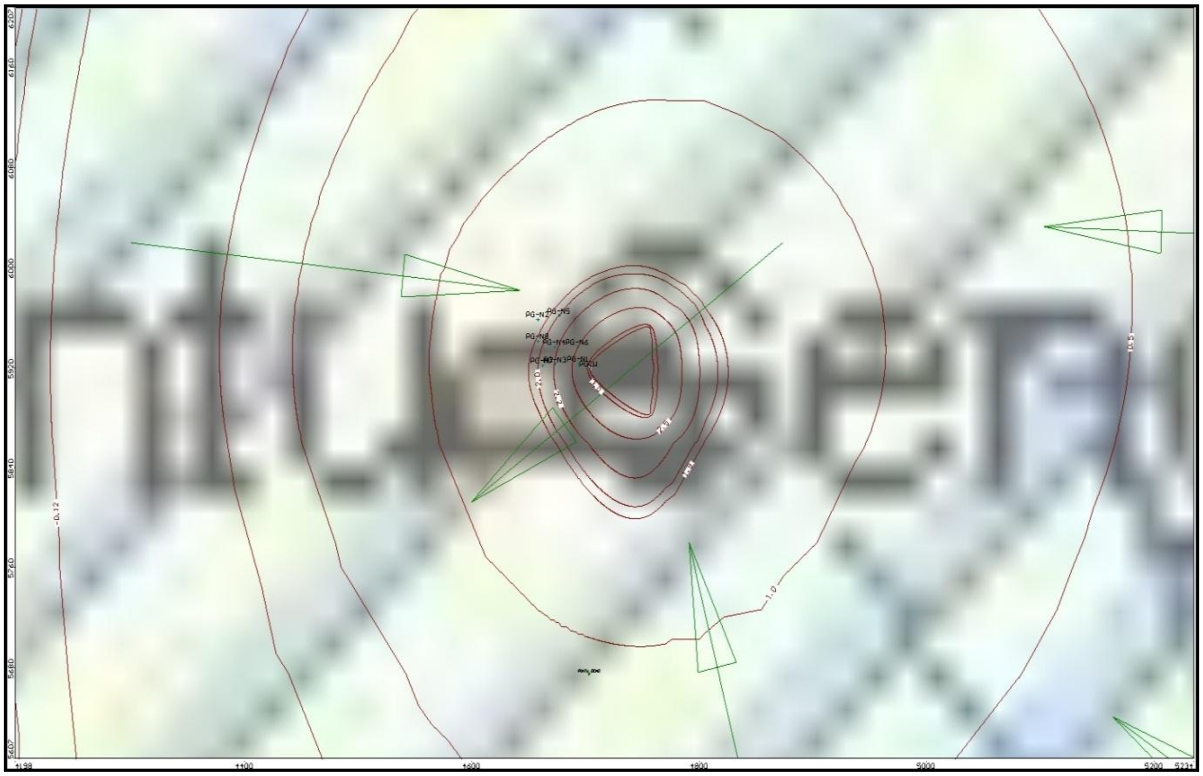

Figure 4.40: Impact of natural condition of the horizontal well (PGHCW) when it set up at - 3m depth on the surrounding of 300-meter radius from the Pintu Geng well-field

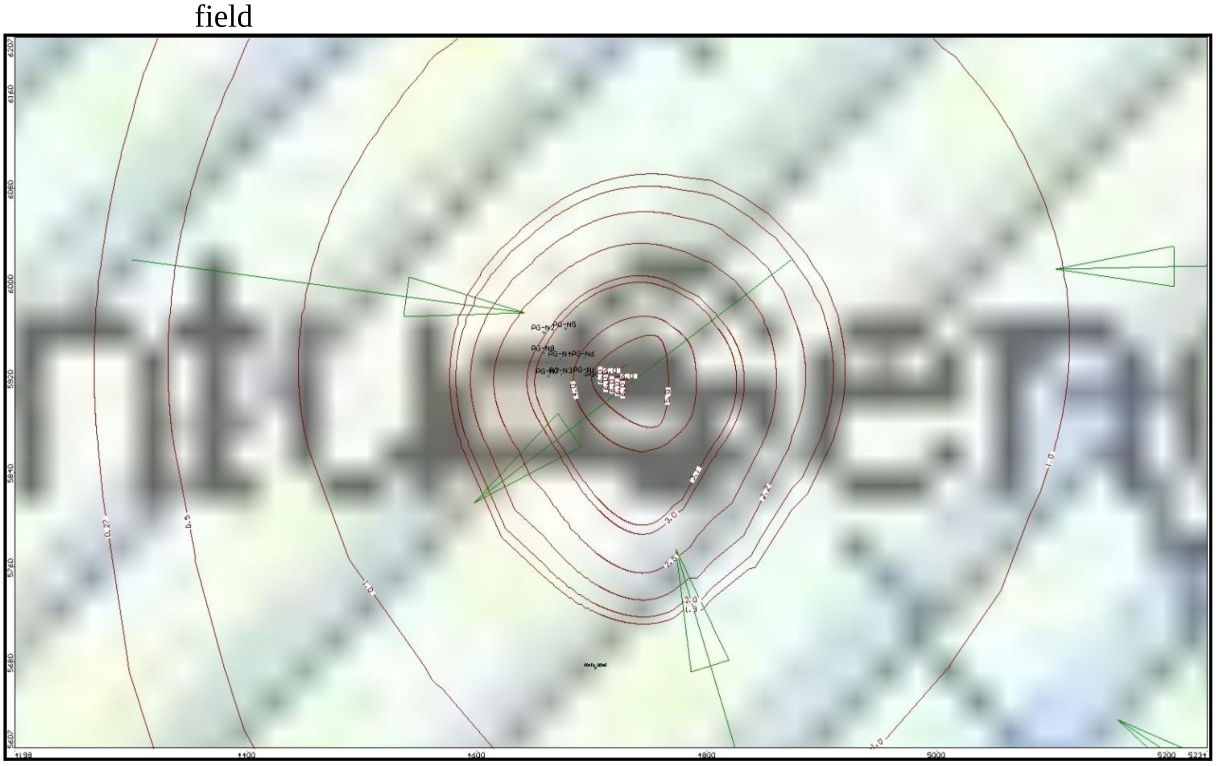

Fig. 4.41: Impact of natural condition of the horizontal well (PGHCW) when it set up at - 6m depth on the surrounding of 300-meter radius from the Pintu Geng well-field

Table 4.14: Impacts of Different Scenarios of Groundwater Pumping at PGHCW [a]

Item	Number of Collectors (drains)	Drain elevation (m)	Screen location	Drains Discharge Range (m^3/day)	water level in the PGHCW (m)	Drawdown with 300m radius from PGHCW	Remarks
Natural	2	-0.5	-0.4 – -0.6	5,700 – 13,300	-0.5	-	- Balanced water budget at zone 2 [b]
Natural	6	-0.5	-0.4 – -0.6	6,200 – 14,100	-0.47	-	-ditto-
Pumping at 9,000 m^3/day	6	-0.5	-0.4 – -0.6	0.0 – 5,800-	-2.0	Up to 0.27	-ditto-
Natural	6	-2.0	-1.9 – -2.1	14,000 – 20,000	-2.0	-	-ditto-
Natural	6	-6.0	-5.9 – -6.1	25,000 – 108,000	-6.0	0.27 – 1.0	- Balanced water budget at zone 2
Natural	6	-3.3	-3.2 – -3.4	19,200 – 43,700	-3.0	Up to 0.5	- Balanced water budget at zone 2

[a] PGHCW: Pintu Geng Horizontal collector well; [b] Zone 2: Capture zone of Pintu Geng well-field

ii. Impacts of Pengkalan Chepa well-field

It seems that the Pengkalan Chepa well-field will cause a significant seawater intrusion if the previous running capacity of 6462 m^3/day is considered for operation as illustrated in Figure 4.42.

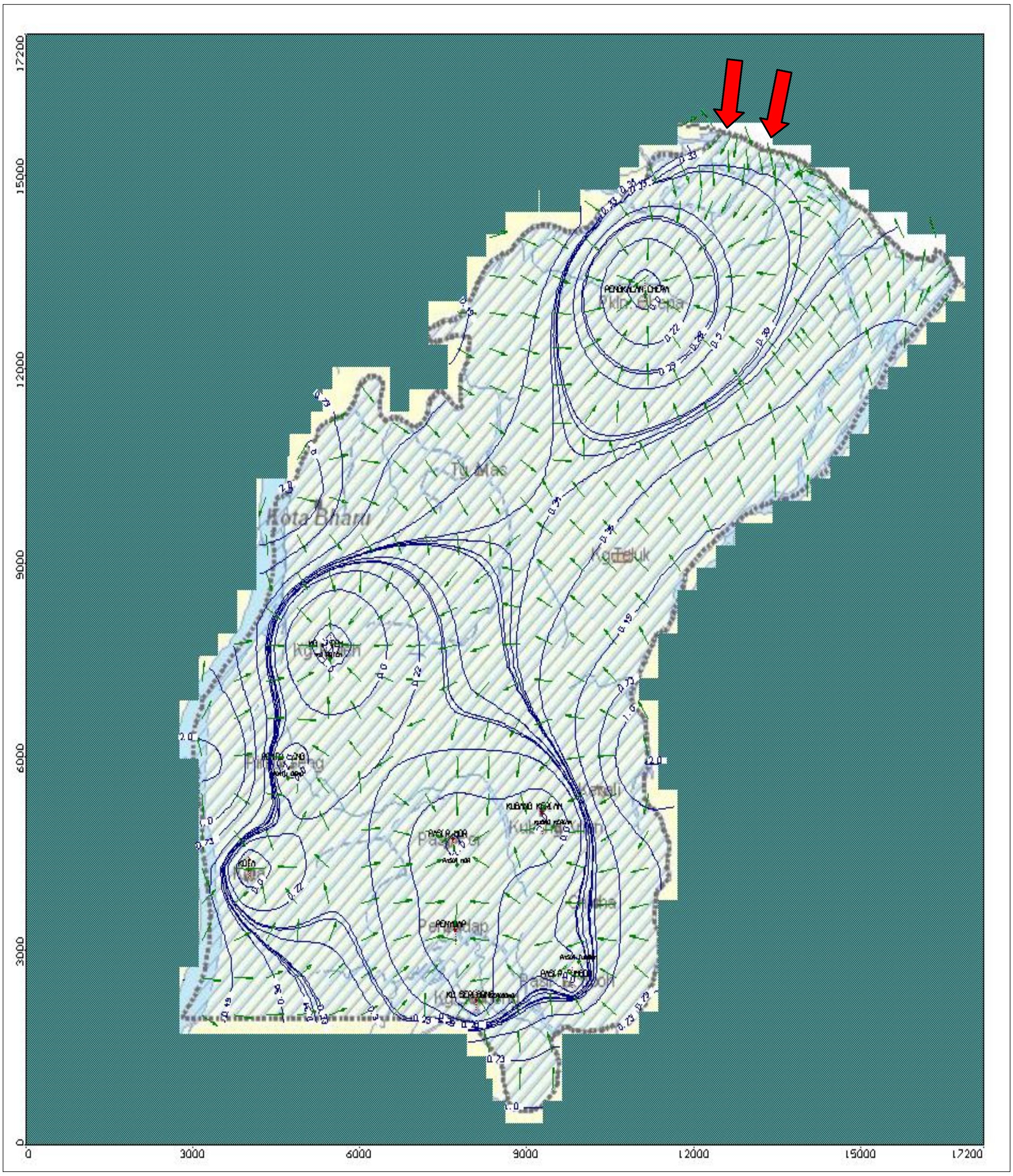

Fig.4.42: Seawater intrusion as a result of pumping Pengkalan Chepa well-field at 6462 m^3/day

4.10.5 Conclusions on Model Results

i. The calibrated and validated MODFLOW models were successfully established in transient state for the North Kelantan Shallow Aquifer only. The first silty clay layer seems to be not continuous where the shallow aquifer exposes downstream of the modelled area, about 1 to 2 km north of Tg Mas and Teluk villages respectively. The area from the South China Sea coastal area up to 1.4 km onshore is covered by fine sand.

ii. The model calibrated using time serious data of the period between January 2000 to December 2005. While the validation period extended from January 2009 to December 2010.

iii. The model demonstrated satisfactory simulation results and labeled with good statistic measures.

iv. The present pumping rate divided the modeled area into two dominant groundwater capture zones i.e. upstream and downstream. The upstream one is further subdivided into eight sub-capture zones that developed around each well-field site due to the present pumping.

v. The model demonstrates that under natural flow condition at -3 m depth, the six collectors (drains) may tap a volume of groundwater ranges between 19,200 – 43,700 m^3/day (12% of stress periods are above 30,000 m^3/day). This rate is feasible if considering that the model is running the pumping for 24 hour a day, while in reality pumping process is much less lasting than in the model.

vi. The model demonstrates that as much as deepening the location of the collectors (drains) is considered i.e. up to -6 m, the more water can be tapped.

vii. The model predicts a drawdown between 0.5 – 1.0 m for the area within 300m radius from the HCW and this value is considered environmentally impact free (maximum allowable drawdown for this area is 3 m).

viii. The model demonstrates that the Pengkalan Chepa well-field will cause a significant seawater intrusion if the previous running capacity of 6462 m^3/day is considered for operation.

4.10.6 Web-based GIS Application on Modeling Results

GIS technology is an effective means of bridging and integrating the information gathered and models results. GIS applications provide an accurate and manageable way of estimating model input parameters and provide an easily updated database for simulations of future conditions. Among the objectives of the GIS integration for model results, are:-

i. Collect data wirelessly, thus reducing data error that may cause catastrophic effect to water management in providing clean and undisrupted water supply.

ii. Extract statistical data, through historical data collection, that will ensure the most precise data to be used for remedial and long term water supply planning

iii. Ensure close monitor on ground water extraction performance, thus eliminating the potential water supply failure and disruption.

iv. Utilise state of the art infrastructure that will ensure the future success of ground water sustainable supply.

In this study, it can be demonstrated that using GIS software like ArcGIS with the intergration of MODFLOW model results, there are few useable modules that be developed in Web-based applications, to further enhance the model results, namely:-

i. As in Fig. 4.43, the area coverage of WIFI or UHF transmissions and internet connectivity area within the study area can be determined for the placement of receivers and transmitters of the radio stations for the telemetry functions using the GIS functions.

ii. A Geographical Information Systems(GIS) prototype model was developed for improving and expediting GWRM monitoring system. Data gathered for the prototype model was gathered from historical databank and on-site wireless data connectivity, with Internet Web-based application. The results of this case study indicate that a GIS for the Air Kelantan is feasible. This web template prototype demonstrated how a GIS and GWRM combined standard data collection with advanced computer capabilities, allowing the users to more easily maintain historical data, predict future environmental impacts more quickly, better optimize their resources, which provided added project control and better response time. The web template prototype is shown in Fig. 4.44 and Fig. 4.45 below.

iii. Statistical analysis with graphical representation can be developed in the same web-based application for managerial use in creating decision-making tools and key performance indicators for the water operator, as illustrated in Fig. 4.46 .

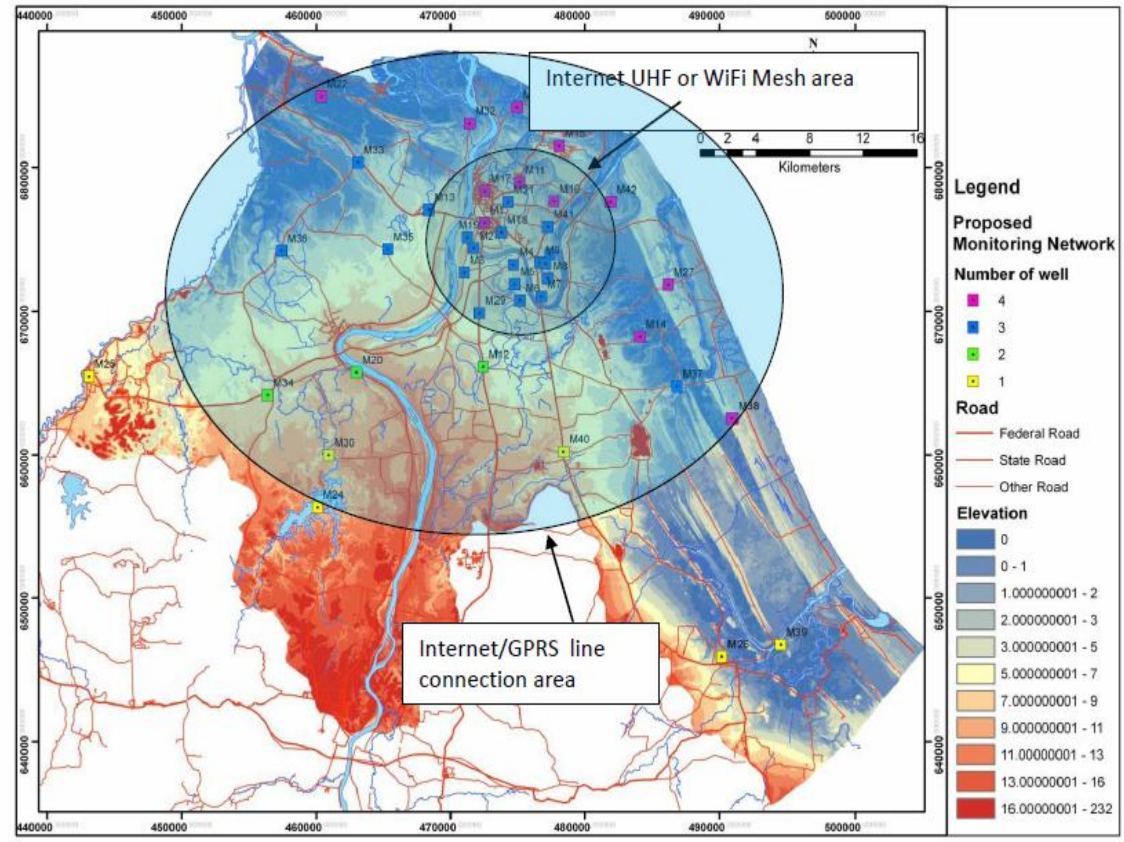

Fig.4.43: Determination of coverage area of WIFI/UHF and Internet/GPRS connectivity in study area.

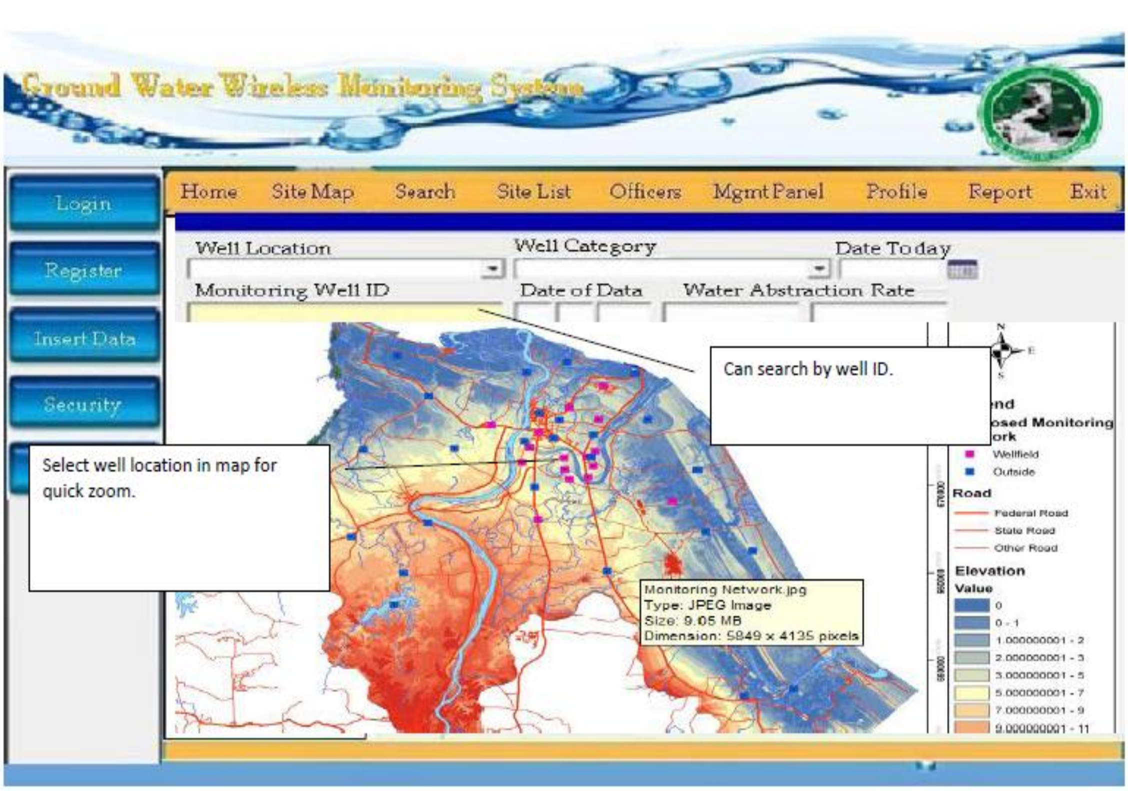

Fig.4.44: Web template of GWRM monitoring system for the study area.

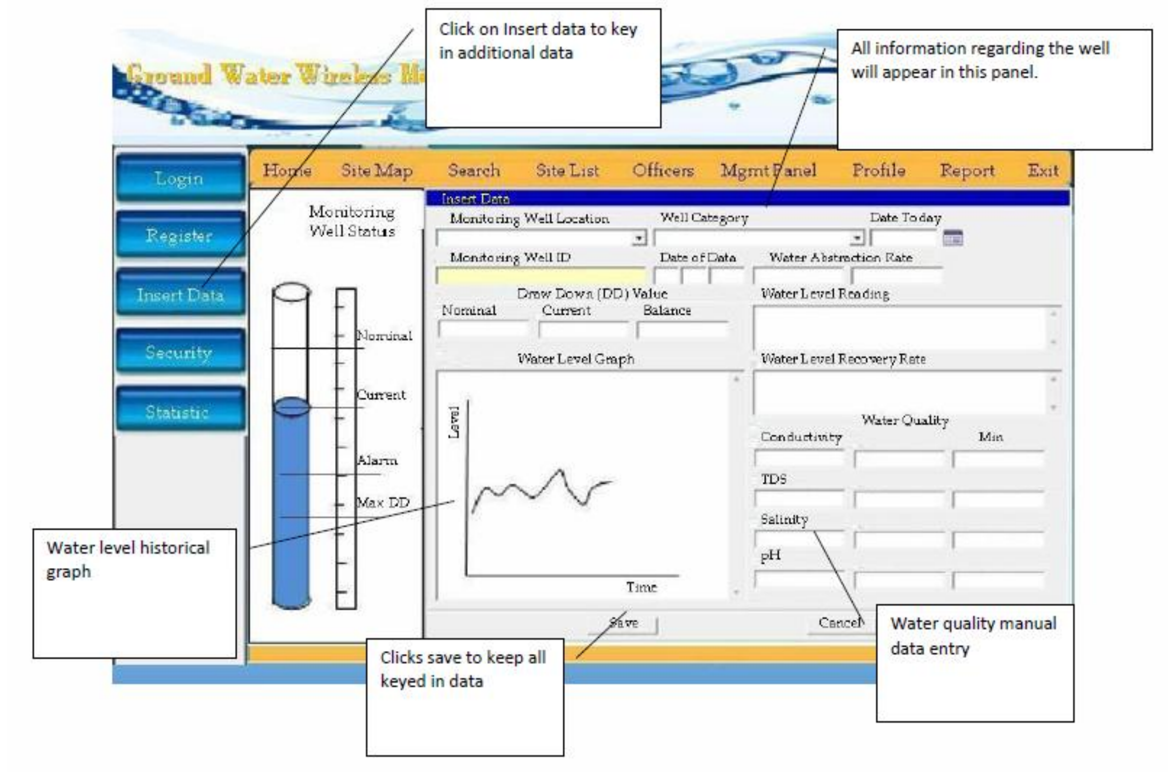

Fig.4.45: Data Management of GWRM monitoring system for the study area.

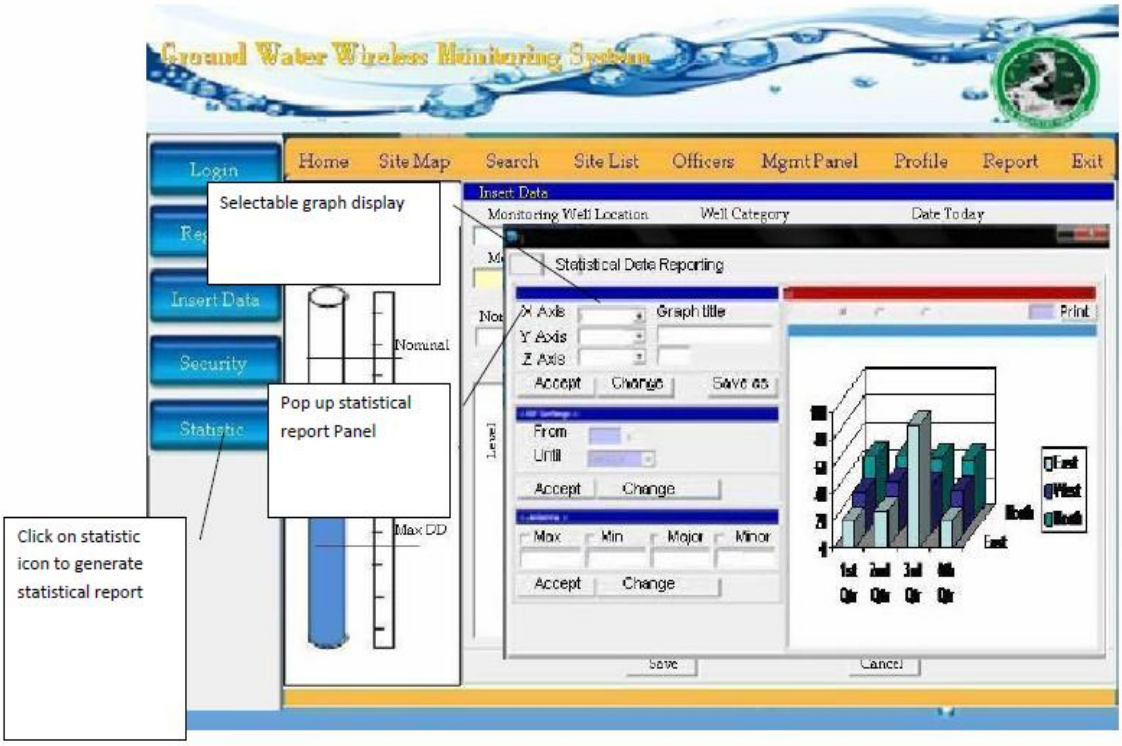

Fig.4.46: Statistical Analysis of GWRM monitoring system for the study area.

iv. A flow diagram of Databases Management and Groundwater Resource Management is illustrated in Fig. 4.47, to better understand the complete process of data input and sharing, for an effective groundwater evaluation and resource planning and management in the future.

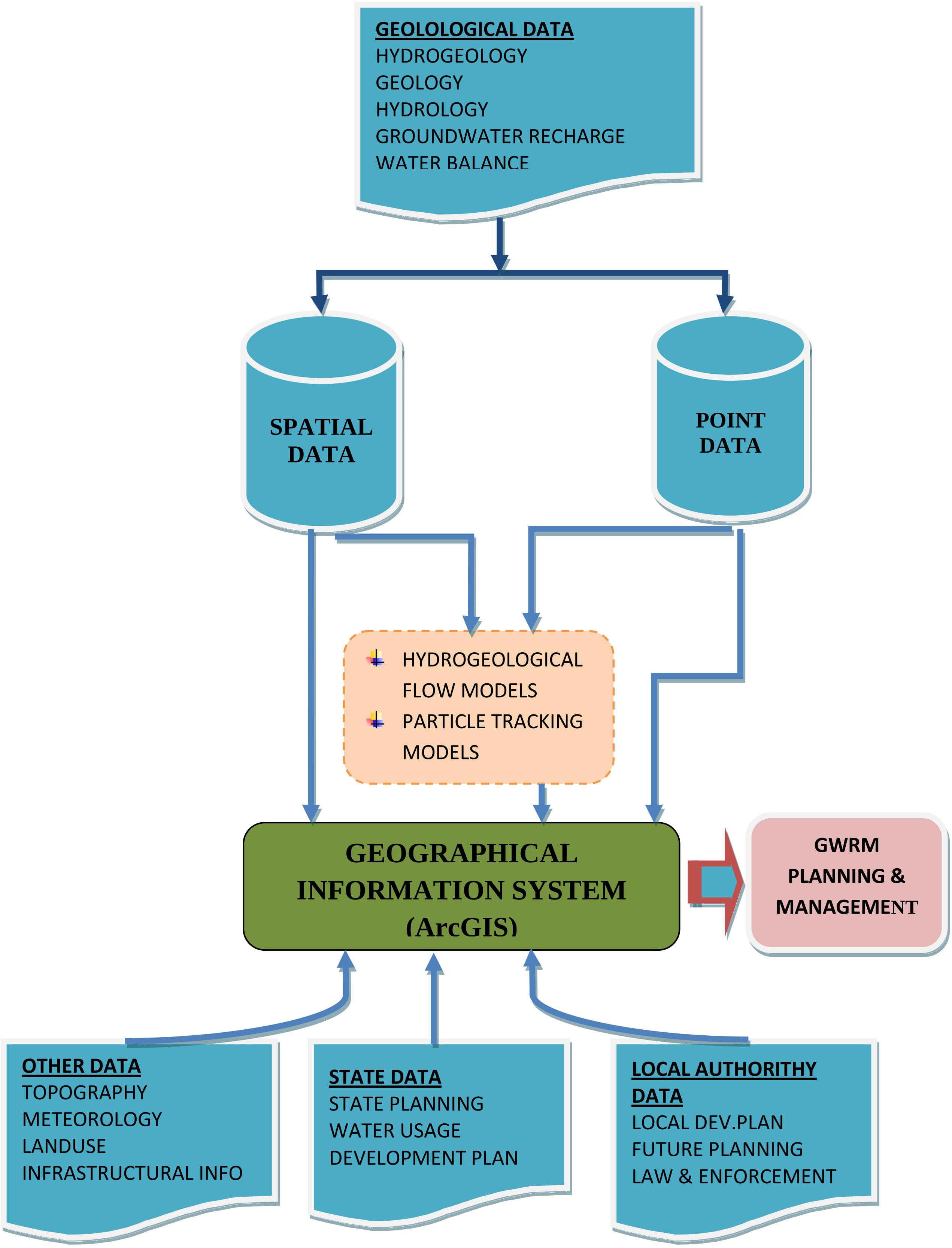

Fig. 4.47: Databases Management and Groundwater Resource Management Flow Diagram

4.11 DISCUSSIONS

There are few issues that can be put forward for discussions on the subject matters, namely:-

i. The organizational framework of the GWRM is an important prerequisite issue for a sound and effective ground water management system. The present weak water conservation and resource management in the state will need a plan to implement the ‘Integrated Water Resource Management’ (IWRM), a framework to ensure that the development needs in potable water from groundwater sources are not at the expense of the environment and its components. This dissertation does not reflect the issue thoroughly, but the mechanism on how to achieve the said plan has been mentioned and discussed. Transformation of the GWRM into a more meaningful system, called the Integrated Groundwater Management System, where it integrates the eco-system elements with the influences it has on groundwater, will be the next agenda of relevant agencies in the state.

ii. With the implementation of GWRM’s system network, the pools of data gathered with more time series data, will enable the administrator to fine-tune the hydrogeological models and develop transient models with more accurate data and entails simulations of different elements and factors. This dissertation has gathered the relevant data based on previous data and recently collected data to develop the up-to-date model in the study area.

iii. The water operator or the custodian authority would be able to take the opportunity to expand and emulate the management system elsewhere and at the same time transverse their businesses outwards.

iv. The Well Head Protection Action (WHPA) will be practically put in place for enforcement functions due to better monitoring abilities of the GWRM system in beaming information on water quality with standards on contaminants content in the groundwater. Alarms functions will be triggered when limits are violated and future sustainable issues on groundwater usage will be managed wisely and systematically.

v. The vulnerability map in GIS format can be prepared with relative data gathered from the implementation of this GWRM system. A vulnerability mapping with reliable and effective management will ensure a realistic and practical groundwater protection programme for the state of Kelantan.

vi. The calibrated and validated MODFLOW models were successfully established in transient state for the North Kelantan Shallow Aquifer only. The future work can be expanded to cover the models in transient state for deep aquifers and regional influence of it.

vii. The establishment of closer cooperation among the stakeholders in databases maintenance and groundwater resource management is inevitable to ensure the sustainability issues in groundwater usage should be effectively addressed. The proposed cooperation framework among the stakeholders of sustainable groundwater governance is described in Table 4.15.

Table 4.15: Proposed Cooperation and Roles of Stakeholders to Sustainable Groundwater Development Framework in the State Of Kelantan.

Governance	Authorithy/Agency
Policy, Programme, Plan 1.National Groundwater Policy 2.Groundwater Development Programme (5yr. Malaysia Plans) 3. Master Plan and Feasibility Studies 4. Kelantan Basin Management Plan	**National Water Resources Council (NWRC), Economic Planning Unit (EPU),** State Economic Planning Unit (UPEN), Treasury, **JMG, NAHRIM**, Forestry Dept., Pejabat Tanah dan Galian (PTG), Department of Environment (DOE), Drainage and Irrigation Dept. (DID), Jabatan Perancangan Bandar dan Desa (JPBD), Local Councils, **Air Kelantan Sdn. Bhd. (AKSB)**
Infrastructure Development (planning, design, construction and maintenance) 1. Groundwater production well 2. Groundwater Distribution	**AKSB**, JMG
Laws/Enforcement 1. Laws and regulations on groundwater development and management 2.Licencing for well drilling, groundwater abstraction and monitoring 3. Pollution Control Enforcement 4. Guidelines and Standards	**State Water Authority**, JMG, DOE, Kementerian Kesihatan Malaysia (KKM)
Monitoring 1.Groundwater Monitoring (comprehensive monitoring, water quality, land subsidence, water level, inflow and outflow) 2. Pollution Control Monitoring 3. Drinking Water Quality Monitoring	**JMG**, **AKSB**, State Water Authority, DOE, KKM
Education and Research 1. Public Awareness/Education 2. Emergency Response Management 3. Research and Development 4. Training	**JMG, NAHRIM, University**, Local Councils, Schools, DOE, NGO (MWA etc), DOE, District Office, State Water Authority, DID

Note: Lead agencies are presented in bold **letters**.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

In this thesis, the task of having a sustainable management of groundwater particularly for potable use is fully addressed. The adverse impacts to the environment can be minimized or controlled. Groundwater flow modeling and contaminant movement simulation of the alluvial aquifer is needed to support the sustainable groundwater management, as its being named Groundwater Resource Management (GWRM).

It is confident that with the implementation of this system, groundwater sources will be better managed and future development plans for groundwater will be fully controlled within the limits for a safe and sustainable environment.

The study aimed to facilitate the application of groundwater models and software tools, in order to allow better management decision-tools in groundwater management programmes. It has been demonstrated that using groundwater flow model in a pilot area, establishment of monitoring plans and employing software in integration efforts, a significant insights have been achieved on the groundwater management can be implemented for the sustainable groundwater management system. Conclusions drawn from this study can be discussed in the following aspects:-

i. Physical and groundwater properties of the study area; and

ii. Groundwater modeling and application of software.

5.2 PHYSICAL AND GROUNDWATER PROPERTIES OF THE STUDY AREA

The geology of the study area comprises of flat lying Quaternary alluvium with thickness from a few meters, deepening towards the coast to more than 200 meters in the north-eastern area of the state. The alluvium is underlain by granitic and sedimentary or metasedimentary bedrock, the latter consisting mainly of shale, sandstone, phyllite and slate. The granitic bedrock occurs generally east and parallel to the northerly-flowing Kelantan River, while the sedimentary or metasedimentary rocks are confined essentially to the western part.

These two main aquifer systems are hydraulically interconnected especially the first and the second aquifer as they are only separated by semi-permeable strata of silt as demonstrated by pumping test of a test well with screen located at 14-31 m carried out by Noor (1980) at Kampung Chap, Bachok. It is also reported that pumping test carried out at the Kota Bharu Water Works revealed no connection between shallow and deeper aquifers. So, it could be concluded that the interconnection between the shallow and deeper aquifers, or leakage from the lower or upper aquifers depends significantly on the lithology of the aquifer at that particular location. However, data gathered in this study indicate strongly that there is significant interconnection between the upper and lower aquifers.

The aquifers consist of interbedded medium-sized sand to medium-sized gravel as well as some coarse gravel and the scale of interbedding varies from place to place. The percentage of course materials generally increases with depth. The first aquifer is notably productive for exploitation; however, since it is shallow, it is threatened by pollution as the groundwater development is quite concentrated in the populated area of Kota Bharu town. The second aquifer is generally thin and does not contain significant amount of groundwater worth for large-scale exploitation even though in places it forms significantly thick aquifer layer. The third aquifer is the most promising in terms of production and also protection from potential pollution. The fourth aquifer is not distributed throughout the entire region of North Kelantan Basin as it forms the contact with the underlying granite.

It is observed that regionally the groundwater flows north to north-east. However, extensive study carried out to monitor the fluctuation of groundwater level in various layers of aquifer indicates that the various aquifer layers actually show distinct trend of groundwater flow direction.

The permeability of the aquifers ranges from 130 to 2,200 m/d, while the transmissivity ranges from 1,200 to 24,000 m^2/d, significantly higher figures in permeability and transmissivity in the first and second aquifers.

Presently, fresh groundwater supply is obtained from 91 numbers of production wells located at 13 well-fields. Groundwater for these all well-fields is drawn from shallow aquifer system except in Tanjung Mas and new wells at Pintu Geng. In 2009, the total groundwater consumption is 134Ml/d, which constitutes about 41% of the total water production in AKSB's water treatment plants. The demand for groundwater in potable use is at 145Ml/d in 2010 and will increase at pace of 2.5% per year.

It is observed from previous studies that the groundwater in the study area has been contaminated with nitrate, ammonium, pesticides and coliforms, especially in the first aquifer, which is contributed by human wastewater and agricultural activities.

5.3 GROUNDWATER MODELLING AND APPLICATION OF SOFTWARE

Significant estimations and assumptions were made in building up the hydrogeological models in this complexity of the groundwater properties and its surrounding characteristics. In order to model and simulate this complex hydrogeological successfully, the details and data incorporated in the MODFLOW software was carefully studied for a good representation of the real conditions.

The GIS assisted database system has demonstrated to help groundwater management practices such as; proper groundwater resource management in terms of groundwater quality & quantity, Integrated management of water, landuse and the environment; to optimize pumping rates with respect to the capacity of the aquifer system, and to prevent groundwater quality deterioration through proper monitoring & evaluation. This GIS aided management tool is to be used to administer daily groundwater production, contingencies plan, recharge and discharge management, and surveillance on water quality, so as to improve the North Kelantan River basin's area management strategies.

5.4 FUTHER WORK

5.4.1 General

Any plans to further develop the groundwater sources, especially for potable water, the water authority is to engage in the use of this study, as a decision tools for a sustainable groundwater management, hence minimizing any deteriorating elements to the groundwater sources in the future.

The groundwater hydrogeological model is to be used often for the planning and development of future needs of groundwater in the study area, in order to predict the future behaviour of the aquifer systems when subject to additional pumping.

5.4.2 Groundwater Modelling

In order to improve the successful performance of the model, more reliable and accurate data must be made available, which include hydrology data of rivers and water bodies, geophysical data of soil, production figures from wells and hydraulic properties of aquifers.

With the implementation of the installation of more piezometers and monitoring wells in the plan, more accurate information will be gained and administered for the development of finer model creation. This implementation should be carried out soon according to the numbers and locations recommended in this study.

5.4.3 Groundwater Protection Policy

AKSB should have a sustainable policy for the exploitation of groundwater from aquifers, which should be based not on the volume of abstraction, but on the basin's recharge capacity. A mass balance is to be used to evaluate the components of the water cycle, on an annual basis. Detailed hydrological and hydrogeological studies are required to determine the water balance, which would be the ideal steps towards protecting the groundwater resources.

5.4.4 Transport Model On Pollution Movement Prediction

The transport model of the study area on pollution movement prediction is giving protection to the groundwater resources a chance from future quality deteriorating, by having simulated prediction of future changes in resources in cases of point-source contaminations or regional violations.

5.4.5 Assessment Using The Horizontal Collector Well Method Of Abstraction

A horizontal well method of abstraction is an improved method over the conventional method of vertical tubewells, which provides better inflow to an abstraction point and less possibility of deteriorating the ground conditions caused by over pumping in abstraction flow.

Data on aquifer media composition (particle size analysis) should be collected from available literature and augmented with samples collected at the site, as well as data on water properties and lateral well screens are important functions in horizontal collector well system calculations. Simulations using MODFLOW will be suitable to evaluate the suitability and viability of this method in a given area.

5.4.6 A vulnerability assessment

A vulnerability assessment based on hydrogeological aspects from field observations has to be carried out to identify the degree of vulnerability of the groundwater to contamination and potential sources of pollution to the groundwater system in the area. At present there is no groundwater wellhead protection policy being implemented in Malaysia. It is suggested that wellhead areas in Kelantan River Basin should be protected but no definite work was carried out to achieve this goal (Ismail 1993).

5.5 CONCLUDING REMARKS

5.5.1 General

The monitoring network establishment in the northern Kelantan area will eventually represents a regional system designed to monitor changes in the groundwater regime over a regional scale. It is designed to detect point sources of contamination and its effect on the regional groundwater resources. Water quality changes on a regional scale, if any, is usually a slow process and records from several years of surveillance are necessary to establish prevailing trends.

This study is to better understand the importance of a balanced development of groundwater as to preservation of good ecosystems in Kelantan through the establishment of “Groundwater Resource Management (GRWM)” system, with a decision support tool of GIS, a hydrogeological model and database system to handle and store all water resource relevant information, and to establish a monitoring system with observation wells for level and quality of groundwater by evaluation of all existing use of water and redefine sustainable use and regulate permits of abstraction.

Future development of groundwater can be guided by implementation of GWRM system and functions to safeguard any further contamination in a regional basis. This can benefits water operators and water stake-holders in understanding and managing the groundwater resources in the study area particularly.

5.5.2 Groundwater Model

A validated groundwater flow model was created for a groundwater sub-basin within the north Kelantan regional groundwater basin to support the water resources management in the Kelantan State. The first silty clay layer seems to be not continuous, where the shallow aquifer exposes downstream part of the modelled area, some 1.1 km to 1.8 Km to the north of the villages Tg. Mas and Kg. Teluk respectively. Furthermore, the area from the South China Sea coast up to a distance of about 1.4 Km onshore is covered by fine sand.

Overall, the groundwater quality in other areas monitored remains good and is suitable for exploitation for drinking purposes. However, due to rapid urbanisation and industrial as well as agricultural developments, there is an increasing threat of contamination to the groundwater, and groundwater quality degradation over the long term is a potential problem to contend with.